RMI

Methane Emissions Control Series

Industrial and Municipal Wastewater Resource Recovery in China:

Pathways for energy transition and carbon neutrality



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About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 50 countries.

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Introduction

Methane is a short-lived but potent greenhouse gas (GHG), with a global warming potential 28 times that of carbon dioxide over a 100-year time horizon. Mitigating methane emissions is critical to slowing near-term global warming. The United Nations Environment Programme states that to achieve the 1.5°C target outlined in the Paris Agreement, global methane emissions in 2030 need to be reduced by 30%–60% relative to 2020 levels.[1]

Methane emissions primarily come from multiple sectors, including coal, oil and gas, agriculture, landfills, and wastewater treatment. Industrial and municipal wastewater systems are among the major sources of methane emissions, with emissions occurring across the entire system, from upstream septic tanks and sewer networks to the treatment and disposal of wastewater and sludge. Together, these stages account for 5%–8% of global methane emissions.[2]

Over the past two decades, driven by socioeconomic development and growing environmental protection efforts, China has made significant progress in expanding its wastewater collection and treatment infrastructure. The treatment scale of both industrial and municipal wastewater has grown substantially, with continuous improvements in treatment capacity and pollutant removal performance, establishing the world's largest wastewater treatment system.

Building on these achievements, the industry is actively advancing its green and low-carbon transition through a range of innovative approaches, including optimizing treatment processes, improving energy efficiency at treatment facilities, deploying wastewater-source heat pumps and solar photovoltaics, and promoting wastewater and sludge resource recovery. These efforts are creating new opportunities to enhance energy efficiency, reduce GHG emissions, and utilize valuable resources. As a result, the development of the wastewater industry is increasingly moving beyond conventional pollutant removal toward an integrated approach that combines pollution control, GHG emissions reduction, and energy and resource utilization.

Among these low-carbon approaches, wastewater and sludge recovery offers an important opportunity to reduce methane emissions while unlocking energy and resource value. Through approaches such as anaerobic digestion, energy recovery, drying, and incineration, the organic matters from wastewater and sludge can be converted into biogas, biomethane, electricity, and other resources. These approaches can simultaneously reduce emissions and displace fossil fuels, delivering both climate and energy benefits. Since the 12th Five-Year Plan period (2011–15), China has continuously improved policies related to wastewater resource recovery. A set of development requirements has been put forward for wastewater pipe network construction, wastewater treatment, and sludge treatment and disposal, laying a policy foundation for the transition of wastewater systems to resource utilization and low-carbon operation.

Building on policy guidance and active exploration by enterprises, China has developed a relatively strong technical foundation and accumulated practical experience in methane emissions control and resource recovery across its wastewater systems. The sector is now at a critical stage of transition from individual project demonstration to large-scale development. Nevertheless, several practical challenges remain. These include limited information available on methane emissions inventories and resource recovery potential, insufficient economic viability of some mitigation projects, and the need to further develop

market-based value realization mechanisms. Addressing these challenges will be essential to advancing resource recovery and achieving systematic emissions reductions in the wastewater sector.

This report is prepared by RMI, drawing on insights from relevant research institutions and industry experts. It focuses on methane emissions and resource recovery in municipal wastewater and sludge systems, as well as in industrial wastewater treatment and disposal processes. The report reviews the sources of methane emissions and the current status of resource recovery in China's wastewater treatment sector, and analyzes the major bottlenecks and potential opportunities for resource recovery and methane mitigation. The report further investigates the value realization mechanisms of wastewater resource recovery, explores the future development pathways and priority areas for development, and puts forward action recommendations to provide suggested next steps for relevant market participants and policymaking.

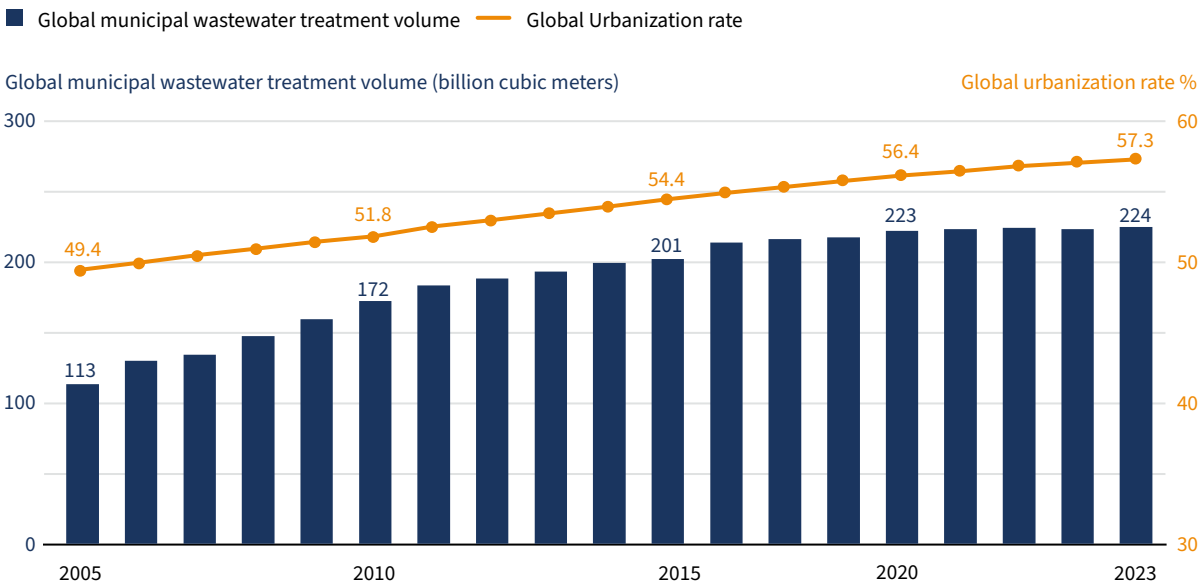
1. Wastewater: From GHG emissions sources to resource recovery hubs

The global wastewater treatment industry is developing rapidly, and its climate impacts are becoming increasingly prominent

Over the past two decades, driven by global population growth and ongoing urbanization, the scale of wastewater treatment has continued to expand, accompanied by rising GHG emissions. Since 2005, the global urbanization rate has increased by approximately 8 percentage points, and municipal wastewater treatment volume has doubled (see Exhibit 1). Wastewater treatment systems have become an essential component of global urban infrastructure. At the same time, industrial wastewater volumes have grown continuously as global industrial production capacities have kept expanding, which increases the scale of wastewater collection and treatment system and puts more pressure on environmental management.

With the rapid expansion of wastewater treatment systems, GHG emissions from the systems keep rising as well. Existing studies estimate that global municipal wastewater treatment plants generate approximately 280 to 360 million tons of carbon dioxide equivalent (CO_2e) GHG emissions annually. If industrial wastewater is considered, total emissions associated with global wastewater systems exceed 1 billion tons of CO_2e per year.[3] Among these emissions, methane is the primary direct GHG. Wastewater systems account for 5%–8% of global methane emissions, making them the world's fifth-largest methane source after agriculture, oil and gas, landfills, and coal, with emissions showing an upward trend every year (see Exhibit 2).

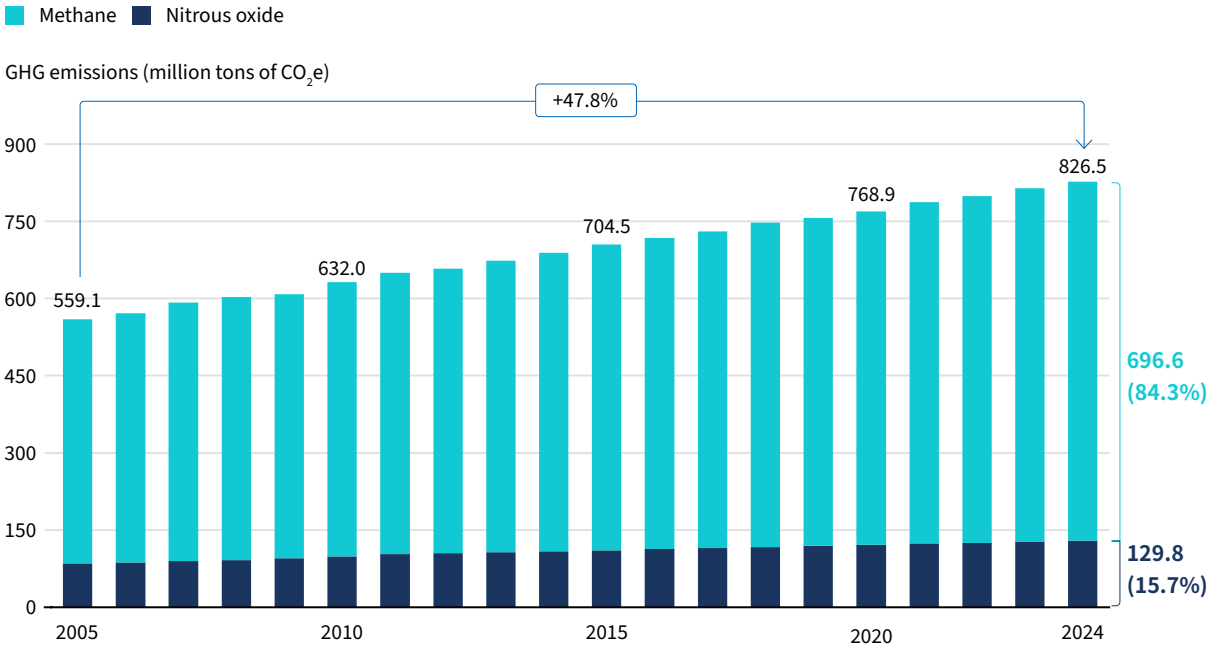
Exhibit 1 **Global urbanization rate and municipal wastewater treatment status (2005-23)**



RMI Graphic. Source: Food and Agriculture Organization, AQUASTAT, https://www.fao.org/aquastat/en/databases/maindatabase/; The World Bank, Urban Population Indicator, https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

Apart from methane, the treatment processes emit nitrous oxicde and consume substantial energy. A study indicates that under different shared socioeconomic pathways and global emissions reduction scenarios, the contribution of wastewater treatment systems to global GHG emissions by the end of this century will be 2 to 17 times the current level.[4] Therefore, reducing methane emissions from the wastewater sector while improving energy efficiency during treatment processes is critical to containing the overall climate impact of the wastewater sector and accelerating global methane emissions control.

Exhibit 2 **Direct GHG emissions from global wastewater sector (2005–24)**



Note: The data includes emissions from both municipal and industrial wastewater treatment.

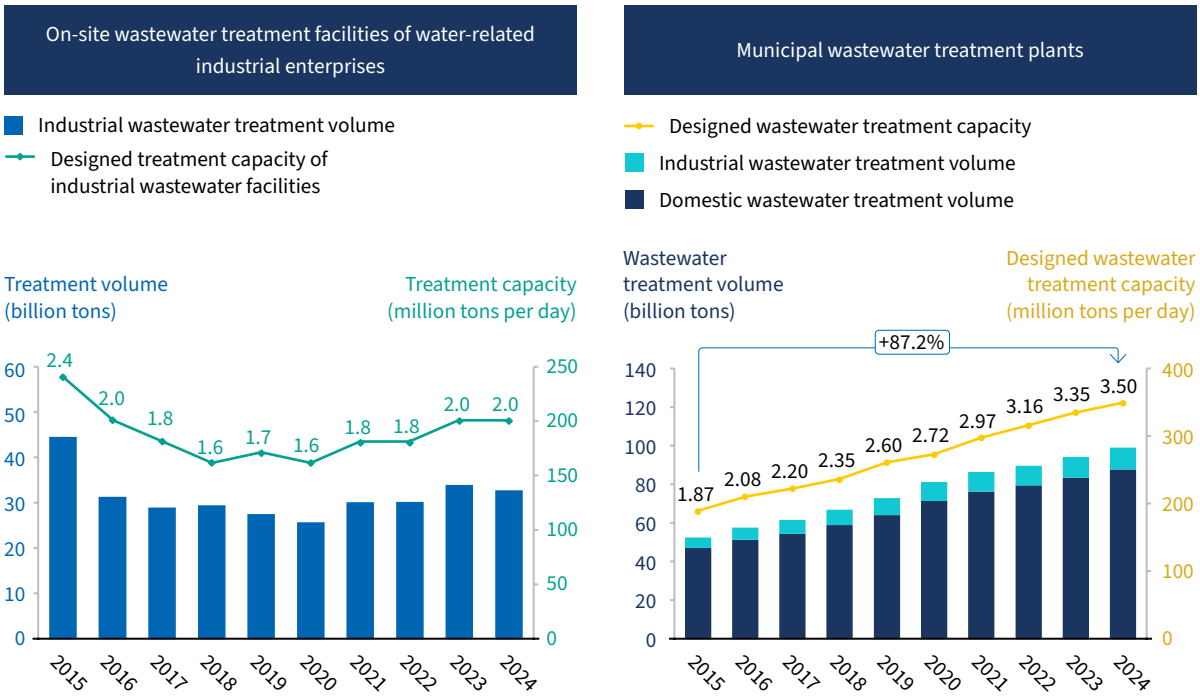
RMI Graphic. Source: M. Crippa et al., *GHG Emissions of All World Countries — 2025 Report*, European Commission, 2025, https://doi.org/10.2760/9816914

Wastewater systems are becoming a key area for climate governance in China

Since the reform and opening-up (1978), China has undergone rapid urbanization. The urbanization rate of permanent residents rose from 21.1% in 1982 to 67.9% in 2025, with more than half of the population migrating from rural to urban areas over the past four decades.[5] At the same time, municipal wastewater treatment systems have seen massive expansion. From 2015 to 2024, the number of wastewater treatment plants in China increased from 6,910 to 15,259, and the annual wastewater treatment volume rose from 53.2 billion cubic meters (m^3) to 98.8 billion m^3, representing an increase of nearly 87%.[6]

China ranks first worldwide in both the quantity and treatment capacity of wastewater treatment plants. Meanwhile, as industrialization advances and pollution control facilities in industrial parks and key sectors keep improving, the overall volume of industrial wastewater treatment remains substantial. In 2024, there were 83,367 water-related industrial enterprises included in China's environmental statistics survey. The designed treatment capacity of on-site wastewater facilities within these enterprises reached 200 million tons per day, and the total industrial wastewater treated throughout the year exceeded 32.7 billion tons (see Exhibit 3).[7]

Exhibit 3 Design capacity and operation status of municipal wastewater treatment plants and industrial wastewater treatment facilities in China (2015–24)



Note: Industrial wastewater in China must be treated to meet discharge standards by wastewater treatment facilities owned by enterprises or industrial parks before being discharged into natural water bodies or further conveyed to municipal wastewater treatment systems for centralized treatment. Therefore, municipal wastewater treatment plants also handle a certain volume of industrial wastewater.

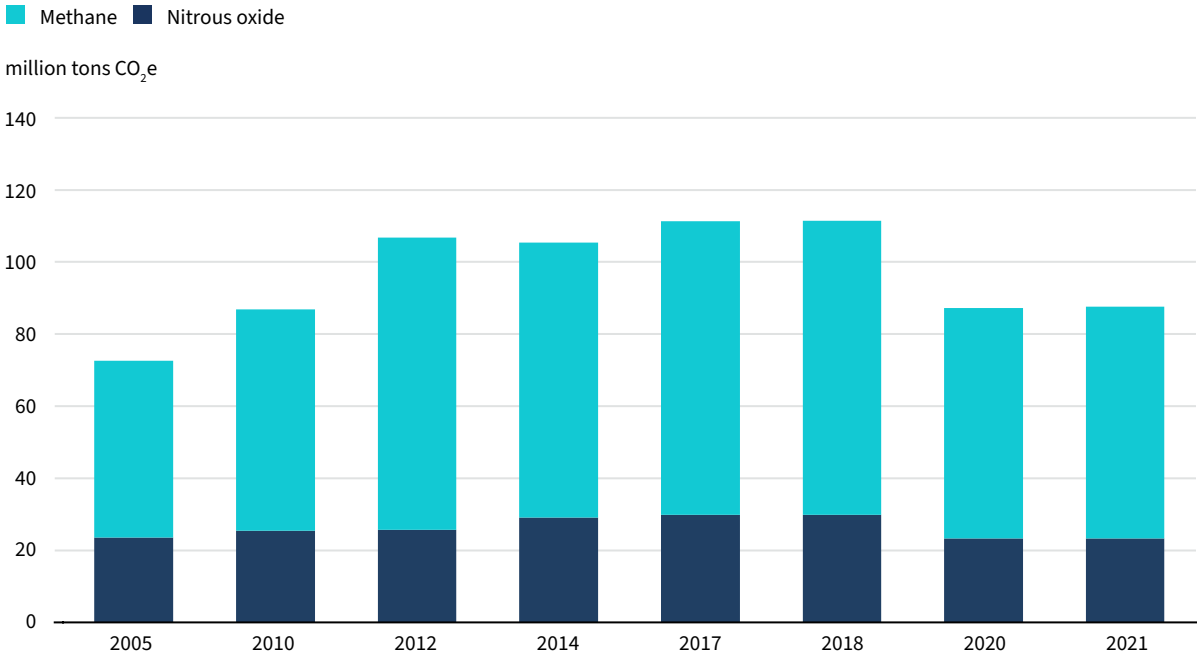
RMI Graphic. Source: China Ecological and Environmental Statistical Yearbooks, **https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/**; and RMI analysis

Wastewater treatment systems are emerging as one of the key sectors for GHG emissions reduction in China. As China's wastewater treatment capacity keeps expanding and pollutant load in wastewater keeps rising, the management of GHG emissions from wastewater systems is becoming increasingly important. Meanwhile, the emissions are influenced by treatment processes, operation conditions, and emission factors, which do not change simultaneously with the variation of wastewater treatment scale. As a result, the systems face continuous pressure of emissions reduction. According to China's national GHG inventory, methane and nitrous oxide emissions from wastewater sector increased from 72.59 million tons CO_2e in 2005 to 87.64 million tons CO_2e in 2021, representing growth of more than 20% (see Exhibit 4).[8] Methane emissions have consistently accounted for a high proportion of the wastewater systems' emissions, reaching 73.4% in 2021. The emissions data shows that the total emissions increased between 2005 and 2018, and decreased from 2018 to 2020–2021, which was related to changes of the industrial wastewater treatment volumes, influent chemical oxygen demand (COD) concentrations, and COD removal volumes.

In addition to its direct emissions, wastewater treatment is an energy-intensive process that consumes large amounts of purchased electricity and thereby produces indirect GHG emissions. Based on a conservative estimate using China's average energy consumption for municipal and industrial wastewater treatment of 0.36 kilowatt-hours (kWh)/m^3 and 0.5 kWh/m^3 separately, the annual power consumption of wastewater treatment in China exceeds 52 billion kWh, with indirect emissions reaching as high as 27 million tons CO_2e.[9] When both direct and indirect emissions are considered, the total GHG emissions from wastewater systems exceed 100 million tons CO_2e.

Based on important targets and national strategies including the dual carbon goals and the outline of the 15th Five-Year Plan (2026–30), the wastewater treatment sector needs to accelerate its transformation. It is necessary to reduce direct emissions of non-CO_2 GHGs such as methane and adopt measures including energy efficiency improvement and renewable energy substitution to facilitate systematic GHG emissions reduction.

Exhibit 4 **Trends of methane and nitrous oxide emissions from wastewater treatment in China**



Note: The global warming potential over 100 years (GWP100) of methane is 28, and the GWP100 of nitrous oxide is 265. The 2005 data is recalculated values from China's first *Biennial Transparency Report*.

RMI Graphic. Source: China's national GHG inventories, **https://unfccc.int/documents/645296**; and RMI analysis

The resource recovery of wastewater and sludge has multiple benefits

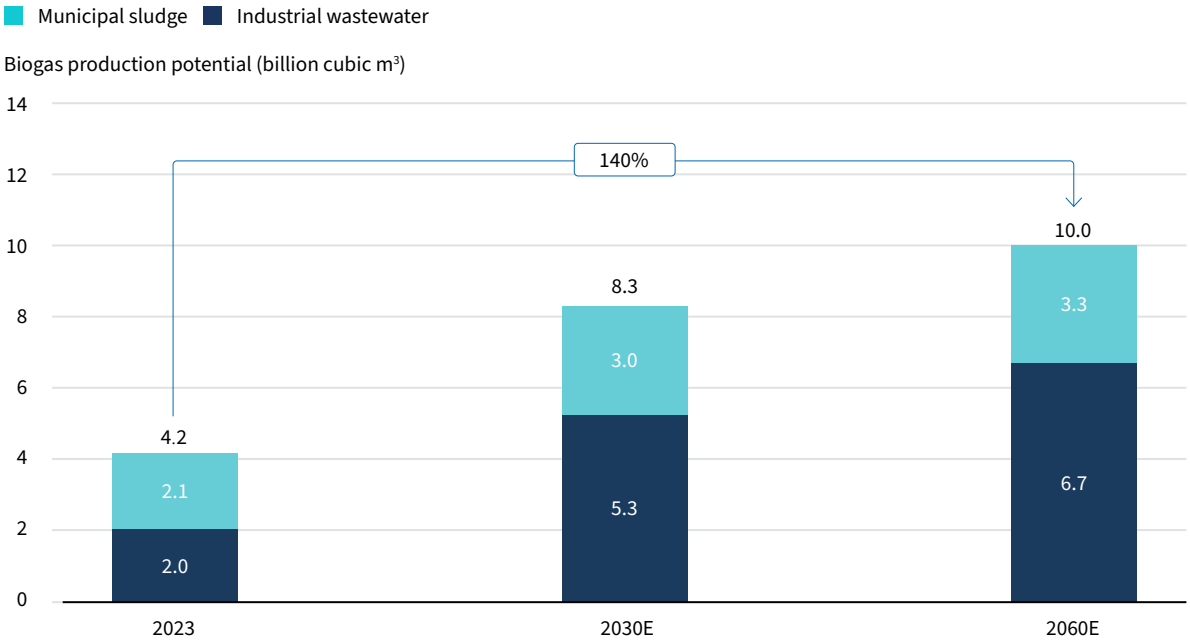
Wastewater systems are not only sources of GHG emissions, they are also critical hubs for resource recovery. Both wastewater and sludge contain large quantities of degradable organic matter, which need to be removed to reduce pollution but also represent a potentially valuable biomass resource. Resource recovery can further tap the resource value of wastewater and sludge, converting waste organic matter into energy products and other resources, extending the focus from water pollution control to resource recovery and circular utilization.

Energy benefit

Full utilization of organic matter in wastewater and sludge enables energy recovery and utilization when pollutants are being degraded, thus increasing the supply of green energy. Anaerobic treatment of industrial wastewater and municipal sludge produces methane-rich biogas. Under suitable anaerobic treatment conditions, an average of 40 m^3 of biogas can be generated from 1 ton of wet sludge (with 80% moisture content), and 400 to 500 m^3 of biogas can be produced per ton of COD removed from high-concentration industrial organic wastewater.

After collection and purification, biogas can be used for power generation and heating to meet the energy consumption needs of wastewater systems, thereby reducing the consumption of purchased electricity, coal, and natural gas, and improving energy self-sufficiency. China's industrial wastewater and municipal sludge have good potential for biogas recovery and utilization. According to estimates, the biogas production potential from municipal sludge and industrial wastewater in China was around 4.2 billion m^3 in 2023 (see Exhibit 5). With the advancement of urbanization and industrial development, this potential is projected to exceed 8 billion m^3 by 2030 and reach 10 billion m^3 by 2060.

Exhibit 5 **Biogas production potential of wastewater systems in China**



RMI Graphic. Source: RMI analysis

Climate benefit

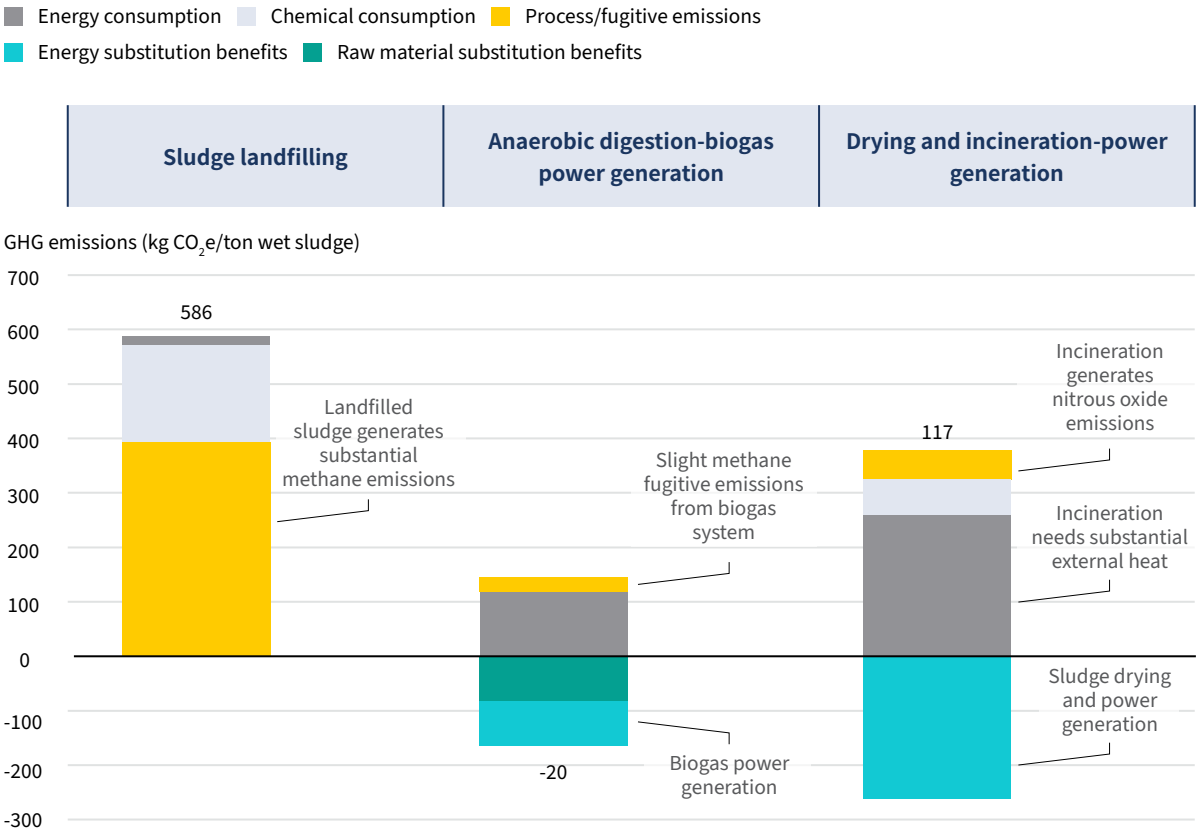
Resource recovery of wastewater and sludge can synergistically reduce methane and carbon dioxide emissions, delivering dual climate benefits from direct GHG emissions cuts and energy substitution. Among relevant approaches, biogas recovery serves as an important pathway for methane abatement in the resource recovery of wastewater and sludge.

The collection and utilization of biogas generated from anaerobic digestion can mitigate direct methane fugitive emissions and convert methane into usable energy. Meanwhile, biogas used for power generation or heating or biogas upgraded to biomethane can replace purchased electricity and fossil fuel consumption at wastewater plants, further reducing CO_2 emissions from energy use. During actual operation, some biogas may be disposed of through venting, flaring, and other means due to insufficient collection and utilization efficiency, leading to certain methane fugitive emissions. In addition, part of the methane can dissolve in the liquid phase and be carried out with digested slurry or effluent, and be released in subsequent treatment and discharge processes. Therefore, improving biogas collection and utilization efficiency can further reduce methane fugitive emissions while energy is being recovered.

For municipal sludge, resource recovery can also cut methane emissions at the source by changing sludge disposal pathways and can generate benefits from energy substitution. There are multiple sludge treatment and disposal options. The conventional practice is landfilling after dehydration. Because sludge still contains a certain amount of degradable organic matter, continuous degradation of sludge under anaerobic conditions after entering landfills will produce substantial methane emissions. Shifting sludge disposal from landfilling to resource recovery pathways such as anaerobic digestion and incineration for power generation reduces organic matter entering landfills and subsequent methane emissions and recovers its energy value. For example, treating 1 ton of wet sludge (80% moisture content), and directly landfilling the sludge after dewatering, will generate approximately 586 kg CO_2e GHG emissions, of which roughly two-thirds is methane.

In comparison, the comprehensive emissions under the sludge incineration pathway stand at around 117 kg CO_2e per ton of wet sludge. Although this pathway cannot achieve negative carbon emissions considering the substantial external energy consumption for dewatering and incineration, it can avoid methane emissions compared to direct sludge landfilling. When sludge anaerobic digestion is adopted with biogas utilization, the comprehensive emissions are about -20 kg CO_2e per ton of wet sludge, which is a negative carbon emissions method at the present stage (see Exhibit 6).

Exhibit 6 GHG emissions of various municipal sludge treatment methods



Note: This scenario considers both direct and indirect emissions. It is assumed that the sludge moisture content is 80%. Thermal hydrolysis is adopted for anaerobic digestion, and the external heat in the drying and incineration route is mainly used for sludge drying.

RMI Graphic. Source: RMI analysis

Renewable resources benefit

Besides its energy and climate benefits, the wastewater system also delivers value in water resources, nutrients, and raw materials. After advanced treatment, wastewater can be turned into reclaimed water for industrial production, municipal use, and ecological water replenishment, alleviating water resource pressure for production and daily life. Nutrients such as nitrogen and phosphorus contained in wastewater and sludge are recyclable. Following anaerobic fermentation, the digestate remaining from wastewater and sludge can be used as a soil amendment to recycle nutrients into the ecosystem. Ash residues from sludge incineration can serve as alternative raw materials for building, further expanding their value in industry and the construction sector. Through energy recovery, GHG emissions reduction, and resource circulation, the resource utilization of wastewater and sludge enables wastewater systems to shift from simple pollution control toward integrated energy and resource recovery.

Climate goals have driven wastewater treatment into a new stage of emissions reduction and resource utilization

China's wastewater management fully considers goals including carbon reduction, pollutant abatement, resource recovery, and circular economy. The wastewater treatment sector is accelerating its transition toward green low-carbon development, resource circulation, and synergistic efficiency improvement.

Early wastewater treatment policies in China focused mainly on promoting the construction of wastewater treatment facilities and pollutant control. Since 2020, with the proposal and accelerated implementation of China's dual carbon goals, systematic carbon reduction and resource recovery have gradually become key development priorities for the industry. Supporting policies on the resource utilization of wastewater and sludge have been successively introduced (see Exhibit 7).

In 2023, the Ministry of Ecology and Environment, together with relevant authorities including the National Development and Reform Commission and National Energy Administration, issued the Methane Emissions Control Action Plan, identifying wastewater treatment as one of the key action areas. The plan:

- Takes resource recovery as a core measure to advance methane emissions reduction.
- Requires enhanced collection and utilization of methane in the wastewater treatment sector, comprehensive improvement of the efficiency of urban domestic wastewater collection and treatment, and steady progress in the safe disposal and resource recovery of sludge.
- Encourages eligible wastewater treatment plants to adopt sludge anaerobic digestion to produce biogas and strengthen biogas recovery and utilization.
- Urges industries with high organic content and good biodegradability in their wastewater to help reduce methane generation by negotiating with urban wastewater treatment plants on pollutant discharge concentrations going into municipal sewer networks (in accordance with laws and regulations).
- Promotes high-efficiency methanogenic technologies for high-concentration organic industrial wastewater paired with high-efficiency treatment technologies.
- Supports eligible methane utilization and emissions reduction projects to participate in voluntary GHG emissions reduction trading.

- Encourages climate investment and financing for methane emissions control projects.

The Action Plan for Carbon Peaking during the 15th Five-Year Plan Period, issued by the State Council in July 2026, also provides clear guidance on wastewater resource recovery. It proposes to "vigorously promote resource-circular production models, strengthen comprehensive waste utilization, cascade energy utilization and recycled water use, and advance the resource recovery of wastewater, waste gas, waste liquid, and solid residues." In addition, policy documents, including the 14th Five-Year Plan for Urban Wastewater Treatment and Resource Utilization, the 14th Five-Year Plan for Circular Economy Development, and the Implementation Plan for the Harmless Treatment and Resource Utilization of Sludge, set out targets such as significantly improving the resource recovery level of wastewater and sludge, encouraging energy and resource recovery from sludge, promoting resource utilization of industrial wastewater, cutting down sludge landfilling scale, and supporting the use of sludge incineration ash as a building material.

Driven by multiple policies covering the dual carbon goals, methane emissions reduction, circular economy, and wastewater resource recovery, the development objective of wastewater systems is gradually shifting from simple pollution control to the coordinated advancement of pollution abatement, carbon reduction, and resource recovery. This transition accelerates the transformation of wastewater systems from end-of-pipe treatment facilities into integrated low-carbon and resource-recovering systems.

Exhibit 7 **Policies for wastewater system resource recovery in China**

Title	Issuing body	Release date	Key contents
Action Plan for Carbon Peaking during the 15th Five-Year Plan Period	State Council	2026	• Strengthen the comprehensive utilization of waste, cascade utilization of energy, and enhance recycling of water resources. • Promote the resource utilization of wastewater, waste gas, waste liquid, waste residue, and other by-products.
15th Five-Year Plan for Circular Economy Development	National Development and Reform Commission	2026	• Promote the upgrading of the circular economy industry, reduce resource consumption and carbon emissions, and improve resource utilization efficiency. • Set a goal that by 2035, a high-quality development system for the circular economy will be basically established, and the utilization efficiency of major resources will reach the internationally advanced level.
Regulations on Water Conservation	State Council	2024	• Instruct local governments at or above the county level to make overall plans for and construct infrastructure for wastewater resource utilization to promote wastewater recycling. • Advise industrial enterprises with high water consumption to gradually adopt technical measures for advanced wastewater treatment and reuse.

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Title	Issuing body	Release date	Key contents
Methane Emissions Control Action Plan	Ministry of Ecology and Environment, National Development and Reform Commission, National Energy Administration	2023	• Strengthen the collection and utilization of methane in the wastewater treatment sector. • Encourage qualified wastewater treatment projects to adopt sludge anaerobic digestion and other methods to produce biogas and enhance its recovery and utilization.
Implementation Opinions on Promoting the Synergistic Improvement of Pollution Reduction and Carbon Mitigation in Wastewater Treatment	National Development and Reform Commission, Ministry of Housing and Urban-Rural Development, Ministry of Ecology and Environment	2023	• Carry out desilting and maintenance of sewage pipelines in a scientific manner to reduce methane emissions. • Conduct energy-saving and carbon reduction retrofits, expand the application of renewable energy, and encourage wastewater (sludge) treatment plants to build their own renewable energy facilities and participate in green certificate trading. • Reduce the scale of sludge landfilling and actively adopt alternative treatment schemes such as resource utilization. • Strengthen the recovery and utilization of sludge biogas, promote biogas for combined heat and power, popularize sludge land application, and drive the utilization of sludge incineration ash as a building material and its resource recovery. • Propose building 100 green and low-carbon benchmark wastewater treatment plants with efficient recycling of energy and resources by 2025.
Implementation Plan for the Harmless Treatment and Resource Utilization of Sludge	National Development and Reform Commission	2022	• Reduce the scale of sludge landfilling and promote energy and material recovery. • Recommend sludge composting, biogas for combined heat and power, and sewage source heat pump technologies, and encourage the utilization of sludge incineration ash as a building material.
14th Five-Year Plan for Urban Wastewater Treatment and Resource Utilization	National Development and Reform Commission, Ministry of Housing and Urban-Rural Development	2021	• Set a goal that, by 2035, the harmless disposal of sludge will be fully realized, and the level of resource utilization of wastewater and sludge will be significantly improved. • Encourage the energy and resource recovery of sludge and promote the utilization of sludge incineration ash as a building material.
14th Five-Year Plan for Circular Economy Development	National Development and Reform Commission	2021	• Promote the codisposal of sludge, kitchen waste, and garden waste. • Promote the resource utilization of industrial wastewater to achieve green, low-carbon, and circular development.

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Title	Issuing body	Release date	Key contents
Guiding Opinions on Promoting the Utilization of Wastewater Resources	National Development and Reform Commission, Ministry of Science and Technology, Ministry of Industry and Information Technology, etc.	2021	• Focus on promoting wastewater resource utilization in key fields. • Implement key projects for wastewater resource utilization. • Improve the institutional mechanism for wastewater resource utilization.
14th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction	State Council	2021	• Promote wastewater resource utilization and harmless disposal of sludge. • Carry out clean production and resource utilization retrofits of industrial wastewater facilities in key industries.
Implementation Plan for Improving Urban Domestic Sewage Treatment Facilities	National Development and Reform Commission, Ministry of Housing and Urban-Rural Development	2020	• Carry out upgrading and renovation of wastewater treatment plants and actively promote wastewater resource utilization. • Encourage the adoption of the sludge disposal mode of biomass utilization + incineration in large and medium-sized cities with scarce land resources, and promote the utilization of domestic sludge incineration ash as a building material.

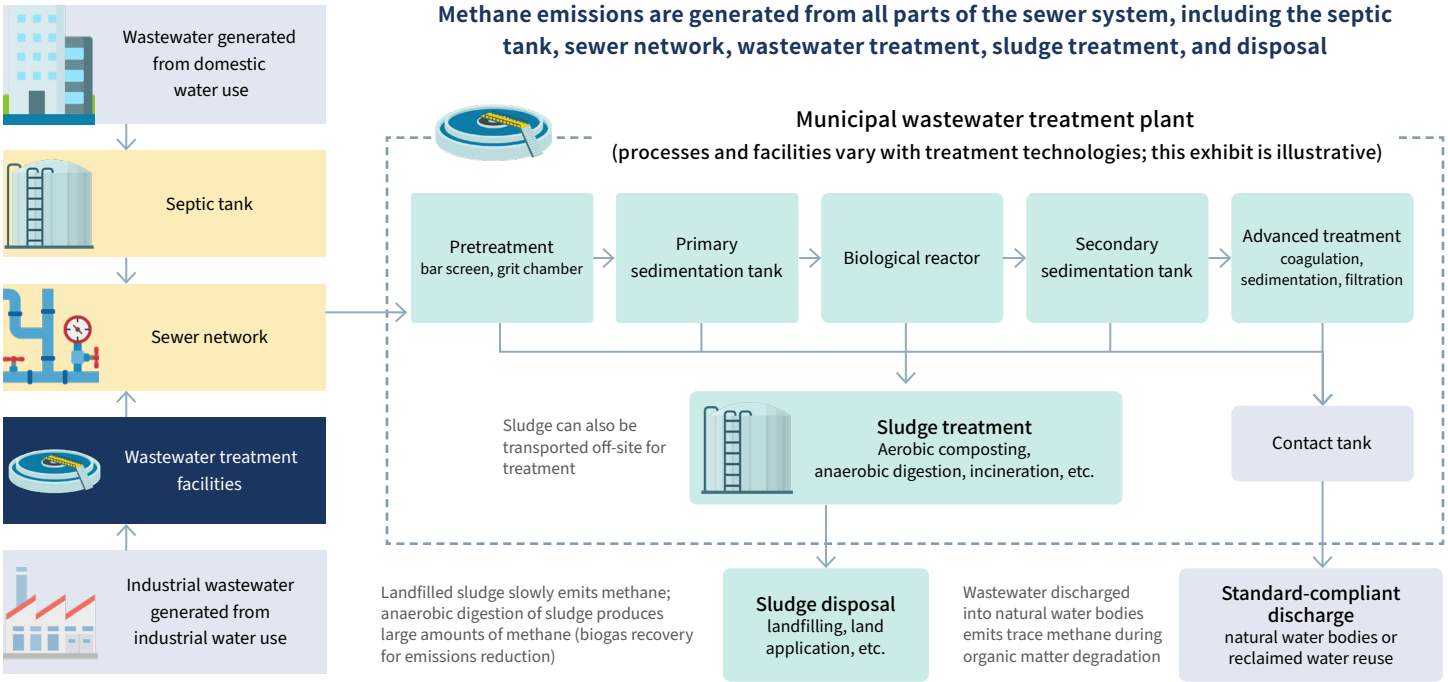
RMI Graphic. Source: Compiled from public data by RMI

2. Resource Recovery of Wastewater Systems: Status quo, challenges, and opportunities

Status of methane emissions reduction and resource utilization

Methane emissions from China's wastewater sector run through the entire process from wastewater generation to standard-compliant discharge in both industrial and municipal wastewater, and resource utilization has become a key direction for methane emissions control. Wastewater in China is divided into two major categories: industrial and municipal domestic. Domestic wastewater generally flows first through septic tanks, then enters wastewater treatment plants via sewer networks for centralized treatment. After complex treatment processes, it is discharged or reused as reclaimed water. Due to higher pollutant concentrations, industrial wastewater is usually subjected to advanced treatment by on-site wastewater facilities within factories. It is then conveyed through sewer networks to municipal wastewater treatment plants for further treatment or directly discharged once meeting discharge standards. Organic matter in wastewater along with anaerobic or anoxic environments are critical conditions for methane generation, and methane emissions can occur at all stages of the wastewater system (see Exhibit 8).

Exhibit 8 **Industrial and municipal wastewater treatment system in China**



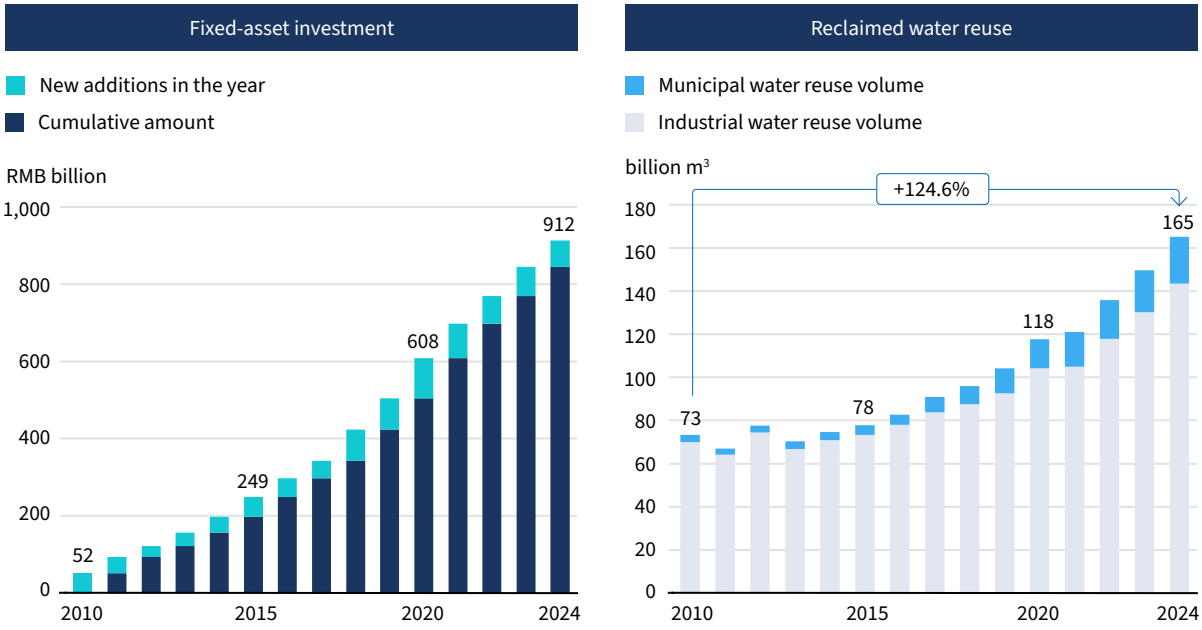
Note: Like municipal wastewater treatment plants, industrial wastewater facilities use multiple processes for pollutant reduction, which are not detailed in this exhibit.

RMI Graphic. Source: RMI analysis

Since the 12th Five-Year Plan period (2011–15), China has continuously increased investment in the construction of wastewater treatment and reclamation facilities. The annual investment in wastewater treatment and reclamation has risen from RMB 52.1 billion (2010) to RMB 67.74 billion (2024), with cumulative fixed-asset investment exceeding RMB 910 billion (see Exhibit 9). After years of sustained investment, China's system for wastewater collection, treatment, and resource utilization has taken initial shape. Measures including reclaimed water reuse, industrial wastewater resource recovery, and enhanced sludge treatment and disposal are being accelerated to continuously improve the emissions reduction and resource recycling capacity of wastewater systems.

China has witnessed rapid development of source reduction and water recycling measures represented by water conservation and reclaimed water reuse, which have become relatively mature approaches. Reclaimed water can realize the recycling of water resources. In recent years, China has continuously promoted water-saving measures and the utilization of unconventional water resources. In 2024, China's industrial and municipal reclaimed water reuse volume reached 165 billion m^3, an increase of more than 124% compared with 2010. Reclaimed water has been widely applied in scenarios including industrial production, urban miscellaneous water use, and ecological water replenishment.

Exhibit 9 **Fixed-asset investment and reclaimed water reuse for urban wastewater treatment in China**



RMI Graphic. Source: *China Urban-Rural Construction Statistical Yearbook,2024*

The municipal wastewater treatment industry is accelerating the deployment and application of low-carbon technologies, and related supporting systems such as performance evaluation standards are being gradually established. In recent years, the wastewater treatment sector has actively explored engineering solutions for green and low-carbon goals and achieved results. Municipal wastewater treatment companies, such as Beijing Drainage Group, Beijing Enterprises Water Group, Capital Group, and China Water, have abundant experiences in resource recovery of sludge, which lay a solid foundation for promotion and application of related technologies. Government authorities have also issued a series of policies and standards to promote low-carbon development in the industry, leading to the construction of 45 benchmark green and low-carbon wastewater treatment plants.

Meanwhile, the industry is gradually forming a technical supporting system linking carbon accounting methods, emissions data, performance evaluation, and demonstration applications. The national standard *Performance Evaluation for Synergistic Carbon Reduction — Urban Wastewater Treatment* (GB/T 46725—2025) was officially released in 2025. It establishes a performance evaluation framework for wastewater treatment plants from multiple dimensions including pollution control, energy conservation and consumption reduction, energy optimization, resource recycling, and management coordination. *Requirements for Greenhouse Gas Emissions Accounting and Reporting — Part 55: Domestic Wastewater Treatment Enterprises* is currently pending approval. Relevant technical documents such as those for methane emissions data reporting of domestic wastewater treatment facilities are also under continuous development.

Companies are also actively promoting methane resource recovery in industrial wastewater. Industrial wastewater is characterized by significant intersectoral variations with different treatment technologies, and methane emissions are mainly from anaerobic processes. Relatively mature practices of anaerobic treatment and biogas recovery have been established in some sectors such as papermaking, food production, and brewing (see Exhibit 10). Some enterprises adopt anaerobic processes to treat high-concentration organic wastewater, and the generated biogas is used for power generation, heat supply, or natural gas substitution, achieving synergy between wastewater treatment and the energy demands of industrial production. For such projects, biogas recovery can simultaneously deliver pollutant abatement, energy substitution, and methane emissions reduction benefits. Nevertheless, current relevant practices are still mainly driven by energy conservation, cost reduction, and pollution control compliance. Systematic practices covering methane emissions reduction have not been formed and widely applied in the sector.

Exhibit 10 **Methane resource recovery practices of companies in the municipal and industrial wastewater sector**

Sector	Enterprise name	Emissions reduction and resource recovery actions
Municipal wastewater	Beijing Drainage Group Co., Ltd	Beijing Drainage Group has built five sludge treatment centers — Gao'antun, Gaobeidian, Huaifang, Xiaohongmen, and Qinghe second plant. The total daily treatment capacity is 6,128 tons, and the annual biogas production is 80 million m^3, which is used to generate electricity and heating.
Municipal wastewater	Beijing Enterprises Water Group Limited	Beijing Enterprises Water Group's sludge treatment plant in Beidaihe New District employs a multi-stage/phase-separated anaerobic digestion process. After purified, a portion of the biogas generated from the process is used to preheat the raw sludge in the pretreatment unit, while the remaining portion can be used as vehicle fuel.
Municipal wastewater	China Water	Qianjiang Water Resources Development's Xinghai sludge treatment and disposal phase I project in Ninghai county adopts a multi-stage/phase-separated anaerobic digestion process combined with advanced dewatering technology. The biogas generated during anaerobic digestion is desulfurized and then used for power generation. The waste heat generated during power generation is recovered and recycled to heat the high-temperature and mesophilic digestion tanks. The electricity generated from biogas is connected to the power supply system of the Chengbei wastewater treatment plant for use in its operation. Qianjiang Water Resources Development is controlled by China Water.

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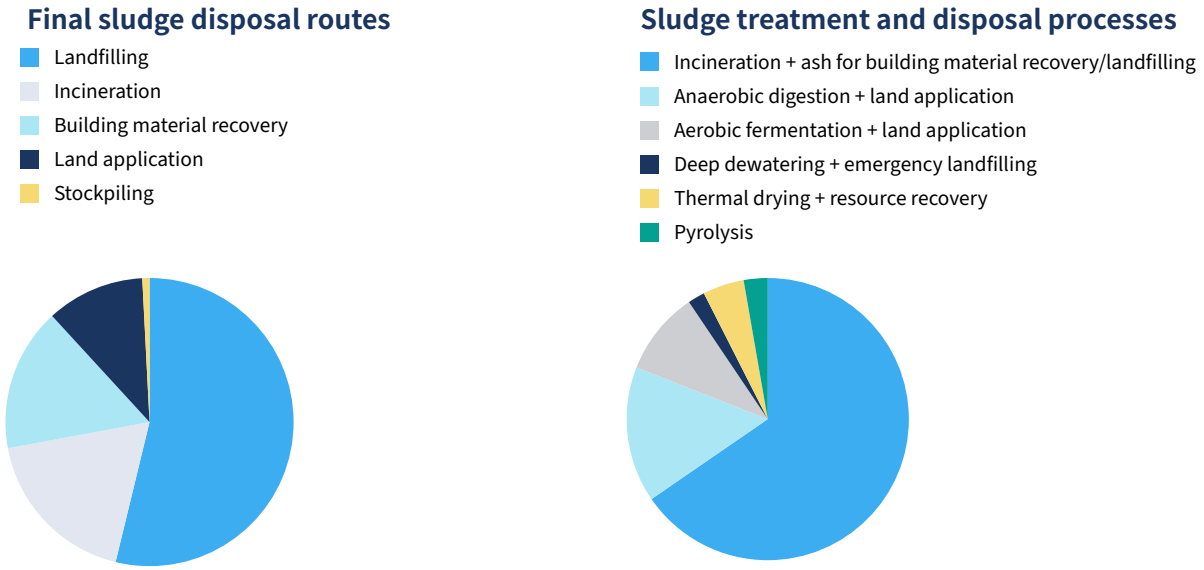
Sector	Enterprise name	Emissions reduction and resource recovery actions
Brewing	Tsingtao Brewery	Tsingtao Brewery cooperates with Qingdao Water Group Tuandao Wastewater Treatment Plant. High-concentration brewery thermal coagulum and municipal sludge undergo anaerobic codigestion for biogas production. The annual biogas yield exceeds 2 million m^3, with carbon emissions reduction of more than 3,800 tons CO_2e.
Brewing	Luzhou Laojiao	Luzhou Laojiao has installed biogas recovery modules in the wastewater treatment systems of its two major brewing ecological parks, Huangyi and Luohan. The generated biogas is delivered to the energy center for heat supply. The annual biogas recovery volume is approximately 3.5 million m^3, cutting carbon emissions by 51,000 tons.
Papermaking	Zhejiang Shanying Paper Co., Ltd.	Zhejiang Shanying Paper Co., Ltd. purifies and upgrades biogas generated from papermaking wastewater to produce high-quality biomethane, which is fed into the urban gas pipeline network. The annual biomethane output is approximately 24.5 million standard m^3.
Food production	Hebei Yufeng Starch Group	Hebei Yufeng Starch Group operates 10 high-efficiency anaerobic reactors each with a volume of 1,000 m^3. The facility treats 10,000 m^3 of wastewater per day, with an annual biogas output of 12.21 million m^3. The annual revenue from comprehensive biogas utilization reaches RMB 15.51 million.

RMI Graphic. Source: Compiled by RMI based on public information

Sludge treatment and disposal is a key development direction for resource recovery in municipal wastewater system. In recent years, China has formed multiple treatment and disposal routes including anaerobic digestion, incineration, and aerobic fermentation. The sludge disposal structure keeps adjusting, with the proportion of landfilling gradually declining, while routes such as incineration, land application, and building material recovery are continuously developing (see Exhibit 11).

Although these technical routes mainly target volume reduction and harmless treatment, the energy and resource potential of sludge has not been fully unlocked, and methane emissions reduction benefits remain insufficiently realized. This is attributable to the long-standing development pattern in China that prioritizes wastewater treatment over sludge management. In the past, the construction of wastewater treatment facilities mainly focused on wastewater collection and compliance treatment. Some facilities failed to fully consider resource recovery needs such as centralized sludge treatment, biogas utilization, and waste heat recovery during planning and construction stages, leaving subsequent retrofits constrained by space, capital investment, and system integration. During the 13th Five-Year Plan period (2016–20), the planned investment in sludge harmless treatment and disposal facilities reached approximately RMB 29.4 billion, accounting for only about 5% of the total investment in urban wastewater treatment and reuse facilities. Sludge treatment capacities for resource recovery still need to be strengthened.

Exhibit 11 **Proportions of processes and final disposal routes for sludge treatment and disposal projects in China**



Note: The data is as of March 2022.

RMI Graphic. Source: An Yingyu et al., *Sludge Treatment Technology and Engineering Cases of Urban Sewage Treatment Plants*, 2024

Overall, resource recovery in China's wastewater systems is expanding from well-established reclaimed water reuse to energy recovery, sludge resource utilization, and methane emissions reduction. However, there are marked differences in the development stages across different segments. Industrial wastewater treatment already has a certain foundation for anaerobic treatment and biogas recovery, yet systematic practices for methane reduction are still lacking. The municipal wastewater treatment system is relatively mature, while sludge resource recovery remains comparatively backward. More importantly, the existing wastewater governance system is mainly designed around pollutant removal, discharge compliance, and end-of-pipe disposal. The energy, resource, and climate benefits have not been fully incorporated into the planning, investment, and operational evaluation of wastewater systems. To further drive the transition of wastewater sector toward low-carbon development and resource recovery, the industry can build on existing progress, improve the economic viability of resource recovery, and deliver additional emissions reductions.

Challenges and opportunities for accelerating resource utilization

To further promote resource recovery in wastewater and sludge and advance methane emissions reduction, the industry needs to:

- Further identify emissions and resource potential
- Improve the economics of some projects
- Ensure the market recognizes the multiple benefits generated by methane reduction, energy recovery, and resource recovery

The baseline emissions and recovery potential remain unclear

Accurate identification of emissions and resource recovery potential at different treatment stages of wastewater systems is the foundation for assessing the sector's emissions reduction potential and scaling up projects. At present, the relevant understanding in China is mainly limited to national and regional scales, while the data is insufficient for the actual emissions and resource recovery potential of different types of wastewater, sludge, and treatment processes. Affected by variations in water quality, treatment processes, facility scale, and operating conditions, methane emissions, biogas yield, and resource recovery conditions vary greatly across regions and facilities. The key emissions sources, priority areas for resource recovery, and practically developable capacity are still unclear. Meanwhile, sectoral methane reduction targets need further clarification. This prevents enterprises from forming stable expectations regarding regional resource volume, project opportunities, and future market demand. The transition of demonstration projects into replicable and scalable models still faces certain barriers.

The economics of resource recovery projects need to be improved

The practical application of wastewater resource recovery pathways in China is constrained by insufficient resource concentration, high capital investment costs, and inadequate revenue, making it difficult for some projects to generate stable economic returns.

Although the total volume of wastewater and sludge resources in China is considerable, the organic matter content is relatively low and the output per unit resource is limited; this is one of the key factors affecting project economics. The drainage networks in China include combined sewer systems that have structural damages and low efficiency. Meanwhile, part of the organic matter in domestic sewage is consumed during pretreatment in septic tanks, resulting in generally low organic load in the influent of wastewater treatment plants. In China, around 45% of wastewater treatment plants have influent COD concentrations below 200 milligrams per liter (mg/L), compared with 350–800 mg/L in developed countries.[10] Such low influent concentration not only raises the operational cost of wastewater treatment but also restricts the production efficiency of energy resources such as biogas.

Sludge faces the same challenge. The organic matter content of sludge in China is typically around 40%–60% with high sand content, and the average gross calorific value on a dry basis of sludge from some plants is approximately 12 megajoules (MJ)/kg. In contrast, the organic matter content of sludge in developed economies including Europe, Japan, and the United States, generally ranges from 70% to 85%, with an average gross calorific value on a dry basis of 19.02 MJ/kg.[11] For wastewater treatment plants, low organic load directly limits the recoverable energy potential and project revenue.

As public service entities, wastewater treatment plants have small profit margins, while resource recovery requires substantial additional capital and operating costs on top of the existing treatment systems. China's wastewater treatment sector is strongly public service oriented. The revenue per m^3 of treated wastewater ranges from RMB 1 to 2, which can barely cover the costs of wastewater treatment and operation, and sometimes needs to accommodate sludge disposal expenses. Although wastewater and sludge resource recovery projects can achieve favorable energy and economic benefits under stable operating conditions, a complete recovery system has high capital and operational thresholds.

Project construction normally requires additional equipment such as gas collection and purification units, energy utilization facilities, and tail gas treatment devices, in addition to land procurement, leading to relatively high up-front capital investment. In China, small and medium-sized facilities account for a

large proportion of wastewater treatment plants. Plants with a daily treatment capacity below 50,000 m^3 make up nearly 90% of the total.[12] The cash flow generated by enterprises from conventional operations is generally insufficient to support the up-front investment in resource recovery projects. Existing completed projects are mostly concentrated among large and medium-sized wastewater treatment operators. An economically viable and replicable business model has not yet been widely established.

Insufficient industrial synergy and inadequate valorization of emissions reduction and energy benefits

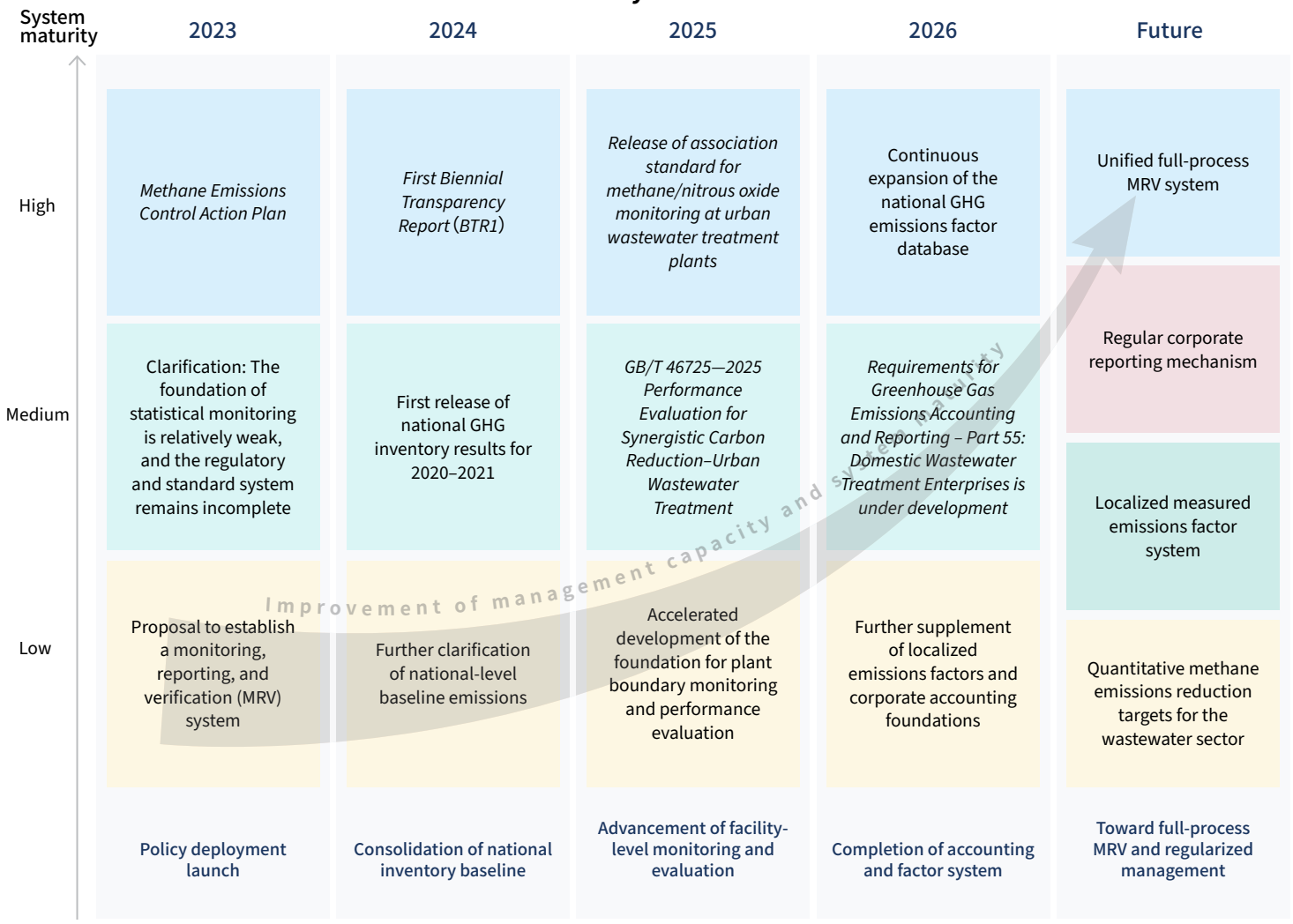
Resource recovery of wastewater and sludge can mobilize participation from multiple sectors including wastewater treatment, energy, industry, and agriculture. However, current practices are largely confined to individual sectors and stand-alone facilities, with insufficient cross-industry synergy and weak linkages in resource utilization. Wastewater resource recovery is mostly carried out by wastewater treatment plants as the sole operator, and existing equipment capacity and resource demand from other industries have not been fully connected. Furthermore, products generated from resource recovery projects, such as biogas, electricity, heat, biogas slurry, nutrient soil, and incineration ash, need to match downstream market demand. Restricted by production scale, transportation distance, safety, and other factors, most of these products are consumed on site, or external sales can be achieved only with subsidies.

Market mechanisms provide insufficient support for the benefits of resource recovery and emissions reduction. Resource recovery projects deliver multiple outputs such as green electricity and renewable gas as well as methane reduction benefits, yet these values are not reflected in product premiums or emissions reduction revenues. The benefits for existing wastewater treatment plants mainly come from electricity and coal savings. In contrast, market mechanisms have gradually taken shape for green power, green fuels, and carbon reduction projects. The national voluntary GHG emissions reduction market has been expanding its support for methane reduction projects, with several relevant methodologies released in 2025. Nevertheless, currently there are no directly applicable methodologies for urban sewage, sludge, and industrial wastewater sectors. The emissions reduction attributes of resource recovery projects have not yet obtained corresponding market value.

Development opportunities

Despite the above-mentioned challenges faced by resource recovery in the wastewater sector, the foundation and conditions for resource recovery are steadily improving as relevant policies, technologies, and market environments gradually mature. New opportunities have emerged to further tap emissions reduction and resource benefits. China's monitoring, accounting, and evaluation system for GHG emissions in the wastewater sector is being refined, and the basis for identifying methane reduction and resource recovery projects keeps improving (see Exhibit 12). Some regions and facilities have started accumulating field measurement data, while relevant standards and accounting frameworks are under continuous development. For example, the group standard for on-site methane monitoring at urban wastewater treatment plants (T/CUWA 50060-2025) and *Performance Evaluation for Synergistic Carbon Reduction — Urban Wastewater Treatment* (GB/T 46725-2025) have been successively implemented. *Requirements for Greenhouse Gas Emissions Accounting and Reporting — Part 55: Domestic Wastewater Treatment Enterprises* is currently pending approval. Localized methane emissions factors have been established based on field data collected in Beijing, Shanghai, Shandong, Jiangsu, and other regions. The ongoing expansion of the national GHG emissions factor database will further enrich the sectoral data foundation.

Exhibit 12 Development and prospect of the baseline data system for methane emissions from wastewater systems in China



RMI Graphic. Source: RMI analysis.

With the continuous maturation of resource recovery technologies, gradual enrichment of industrial synergy models, and sustained development of market mechanisms for green energy and emissions reduction, resource recovery in wastewater systems is embracing new opportunities. China boasts a large volume of wastewater and sludge resources. Different types of wastewater and sludge feature distinct resource endowments, generation volumes, and utilization conditions, laying a foundation for exploring site-specific resource recovery models. Among them, some high-concentration industrial wastewater is characterized by high organic content, concentrated sources, and stable generation, creating favorable conditions for anaerobic biogas production and energy recovery. Municipal sludge accumulates organic matter during wastewater treatment and has a relatively stable output, which supports energy recovery and codisposal.

On this basis, strengthened coordination with industrial production, solid waste treatment, and other sectors can further expand application scenarios for biogas, electricity, heat, and other resource-recovered products. Meanwhile, the development of market mechanisms for green fuels and carbon reduction offers new channels to realize environmental benefits such as energy substitution and methane reduction. Subsequent sections of this report discuss key resource recovery models and value realization mechanisms for wastewater and sludge.

3. Value Realization: Resource utilization models and market mechanisms

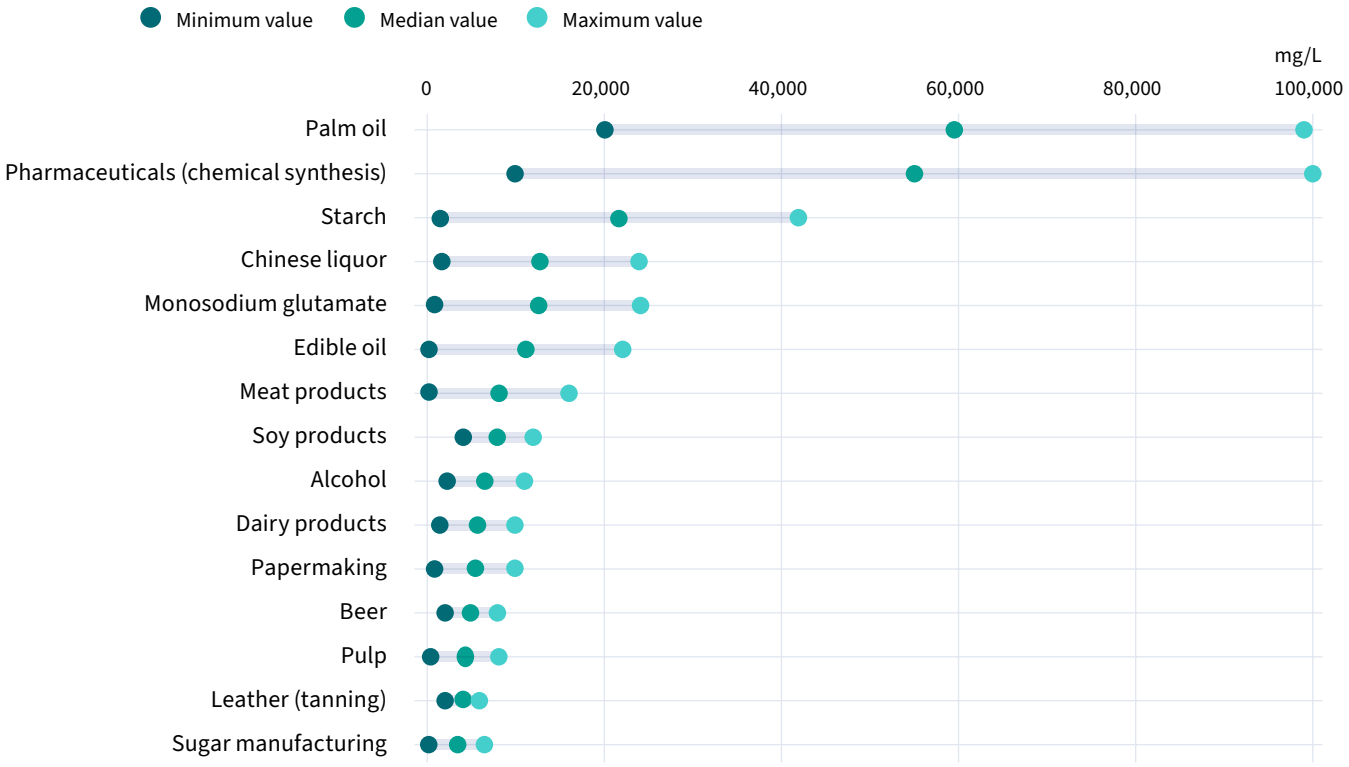
Promote industrial collaboration

Industrial wastewater biogas as a fossil substitute

The treatment of industrial wastewater is not only one of the key sources of energy consumption and methane emissions within industrial production systems, it also contains untapped green energy value. Wastewater generated during industrial production normally undergoes pretreatment, biochemical treatment, and other processes to remove pollutants. Some high-concentration organic wastewater contains abundant biodegradable organic matter. If such wastewater is treated solely by aerobic processes, it leads to substantial energy consumption and high operating costs. Under suitable conditions, combined multistage anaerobic–aerobic treatment can cut costs and improve system efficiency. The anaerobic process produces methane-rich biogas. After collection and purification, the biogas can be directly utilized as an energy source, reducing the demand for purchased energy at wastewater treatment facilities and achieving energy conservation and carbon reduction in industrial wastewater treatment.

High-concentration industrial wastewater with good biodegradability represents a priority area for energy recovery. Industrial wastewater comes from a wide range of sources with substantial variations in water quality. Influent COD, biochemical oxygen demand, biodegradability, salinity, toxic and hazardous substances, and so on, all affect the selection of treatment processes and the operational performance of anaerobic systems. Wastewater with high organic load, good biodegradability, and relatively stable flow rate is more suitable for anaerobic treatment. When other treatment conditions are basically identical, the higher the influent organic load, the more organic matter is available for the anaerobic system, and the greater the theoretical biogas production potential. Therefore, influent COD concentration can serve as one of the key indicators for assessing the energy recovery potential of industrial wastewater. Exhibit 13 illustrates the ranges of influent COD concentrations for wastewater from selected industrial sectors.

Exhibit 13 **Influent COD concentration ranges of industrial wastewater from different sectors**



RMI Graphic. Source: Compiled by RMI from publicly available data

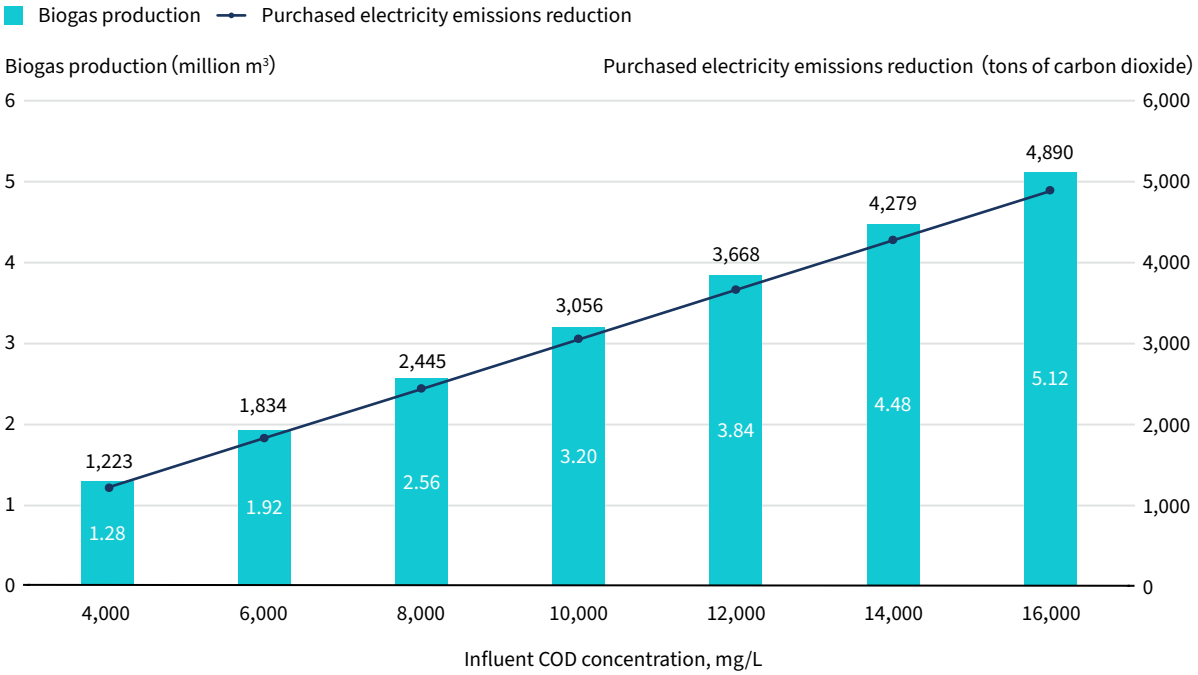
Industry associations and relevant studies indicate that industrial wastewater with promising biogas recovery potential in China is mainly found in light industries, such as liquor brewing, sugar manufacturing, starch production, papermaking, and dairy product sectors, as well as some non-light industries including pharmaceuticals, meat products, and petrochemicals.[13] For enterprises already adopting anaerobic treatment to produce biogas, further tapping the energy recovery value of biogas is feasible. For wastewater with high energy recovery potential where anaerobic treatment has not yet been deployed, the technical and economic feasibility of adding anaerobic treatment processes can be assessed in conjunction with new construction, expansion, or retrofitting of existing facilities.

Biogas power generation is a relatively mature route for biogas utilization from industrial wastewater. The generated electricity is mainly used to meet the energy demand of enterprise production and wastewater treatment facilities, thereby reducing Scope 2 GHG emissions. When biogas recovery and utilization facilities are deployed at existing anaerobic wastewater treatment systems, the levelized cost of electricity is approximately 0.3–0.4 RMB/kWh, if capital and operational costs are considered. This is lower than the cost of purchased electricity for enterprises, demonstrating sound economic performance and energy substitution value. When wastewater treatment capacity, anaerobic process, and operating conditions are roughly identical, the treatment of higher-concentration organic wastewater yields more biogas and greater emissions reduction benefits (see Exhibit 14).

Take light-industry organic wastewater with an annual treatment volume of 1 million m^3 as the baseline. When the influent COD concentration rises from 4,000 to 16,000 mg/L, the annual biogas output increases from 1.28 million to 5.12 million m^3, and the biogas yield per unit wastewater rises from 1.3 to 5.1 m^3/m^3 — a fourfold

increase in both metrics. Meanwhile, the energy substitution effect of biogas power generation gradually strengthens. The purchased electricity emissions reduction per unit of industrial wastewater rises from 12 to 48 tons of CO_2 per 10,000 m^3. Sectors including liquor brewing, edible oil, and pharmaceuticals therefore possess greater room for energy recovery and emissions reduction potential.

Exhibit 14 Effects of influent organic content on biogas production and purchased electricity emissions reduction of wastewater in anaerobic fermentation systems



Note: In this scenario, 1 million m^3 of light-industry organic wastewater with an influent COD concentration ranging from 4,000 to 16,000 mg/L is treated via anaerobic fermentation for biogas recovery and power generation. The system COD removal efficiency is set at 80%, the specific biogas yield is 0.4 m^3 per kg of removed COD, and the biogas power generation efficiency ranges from 1.7 to 2.2 kWh per m^3 of biogas.

RMI Graphic. Source: RMI analysis

In biogas recovery facilities, raising the system's methane recovery efficiency and reducing methane loss in effluent are important for reducing methane emissions. Not all methane generated from industrial wastewater during anaerobic treatment can enter the biogas collection system in gaseous form. Apart from the recovered and utilized biogas, part of the methane remains dissolved in anaerobic effluent and flows into subsequent treatment stages with the effluent. It gradually escapes to the atmosphere during pressure reduction, aeration, exposure to air, and other processes, resulting in methane emissions. Compared with conventional anaerobic reactors such as upflow anaerobic sludge blanket, internal circulation (IC) reactors feature higher organic load capacity and superior gas–liquid separation and biogas collection performance. For high-concentration industrial wastewater treatment, IC reactors are more effective at improving methane recovery efficiency and cutting dissolved methane loss with effluent.

Resource recovery and utilization of industrial wastewater can be further extended to the collaborative use of multisource wastes within industrial parks. A variety of organic wastes are usually generated simultaneously in industrial parks, such as distillers' grains from liquor brewing, food processing residues, waste pulp, and papermaking sludge. These materials can be cotreated with high-concentration organic wastewater via

anaerobic processes. Such cotreatment mode can fully leverage the complementarity of organic matter among different wastes to raise the overall biogas production efficiency and energy supply. The produced digestate and remaining sludge can be further recycled for fertilizer production, material recovery, and other utilization according to their resource properties. In this way, corporate wastewater treatment can be gradually expanded into multisource waste synergistic utilization projects at the park level, further improving resource utilization efficiency and strengthening carbon reduction effects within industrial parks.

Besides internal anaerobic treatment and biogas recovery, industrial wastewater can also be coordinated with municipal wastewater treatment systems to achieve cross-sector utilization of organic carbon resources.

For certain types of high-strength, readily biodegradable organic wastewater generated by industries such as brewing, starch processing, and citric acid production, stand-alone treatment may not be economically viable. This is particularly true for smaller enterprises with limited biogas production, where the investment and operating costs of biogas collection, purification, and utilization facilities can be difficult to justify. As a result, biogas generated by some projects is simply flared, without being put to productive energy use. Alternatively, where wastewater quality requirements and sewer network capacity allow, enterprises can pretreat their wastewater before discharging it into municipal wastewater treatment plants. The industrial wastewater can then serve as a supplementary carbon source, improving the biodegradability of the wastewater entering the treatment process and thereby reducing chemical consumption and associated carbon emissions at municipal wastewater treatment plants.

Some enterprises and regions in China are already exploring models for the coordinated treatment of high-strength industrial wastewater and municipal wastewater. For example, Tsingtao Brewery Group has established a coordinated treatment arrangement with local water utilities. Under this model, hot trub from the brewing process is used as a supplementary carbon source at municipal wastewater treatment plants, while low-strength wastewater is discharged to the plants after pretreatment. As of 2026, this model had been extended to 38 Tsingtao Brewery facilities. Participating breweries have saved RMB 83 million in wastewater treatment costs, while municipal wastewater treatment plants have reduced their expenditure on externally purchased carbon sources by RMB 20 million, generating mutual benefits for both parties.

In the Yangtze River Delta, work also began in 2026 on developing the *Guidelines for the Comprehensive Utilization and Management of Wastewater Carbon Sources*. The guidelines are expected to establish a framework covering management requirements, technical assessment, carbon emissions reduction, and economic benefit accounting. These efforts could help reduce the overall treatment costs for both industrial wastewater generators and municipal wastewater treatment plants, while further unlocking the value of organic carbon in wastewater.

Codisposal of municipal sludge and urban-rural waste resources

China's resource utilization of municipal sludge centers on three main pathways: anaerobic digestion, aerobic fermentation, and drying and incineration. Sludge's high moisture content, its relatively low organic matter content, and limited outlets for end-product utilization mean the treatment mode using sludge as the sole feedstock can restrict resource recovery efficiency and project economic viability. Therefore, a sludge + codisposal model can be explored, in which municipal sludge is cotreated with urban domestic waste, kitchen waste, and rural organic wastes such as livestock and poultry manure and crop straw. Complementary advantages can be leveraged to improve resource utilization efficiency and achieve project-scale effects.

Anaerobic digestion and drying and incineration represent key development pathways to promote the collaborative utilization of municipal sludge and urban-rural waste resources. Anaerobic digestion converts organic matter in sludge into biogas, achieving sludge reduction and stabilization while generating energy products. It is more suitable for codisposal with high-organic-matter wastes such as kitchen waste and livestock and poultry manure. Drying and incineration can improve the overall fuel properties by coprocessing high-calorific-value solid wastes including urban domestic waste, enhancing energy utilization efficiency.

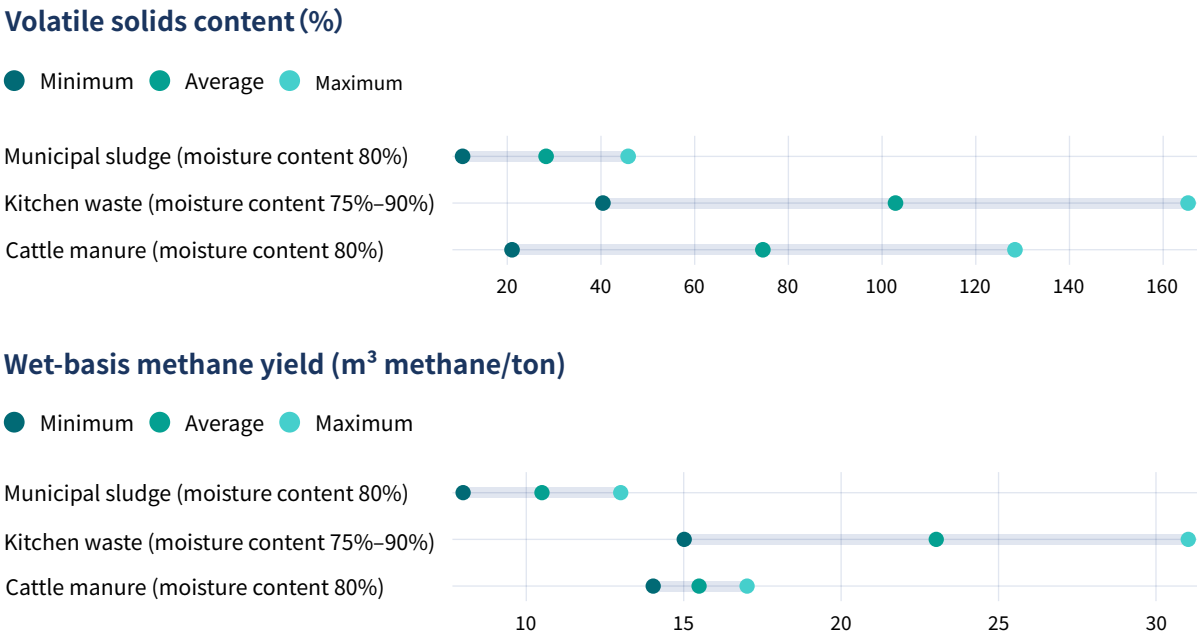
Organic fertilizer is the main product of aerobic fermentation of sludge. However, according to *Organic Fertilizers* (NY/T 525-2026) issued by the Ministry of Agriculture and Rural Affairs, sludge shall not be used as raw material for organic fertilizer production. At the present stage, products from sludge aerobic fermentation are mainly applied in municipal landscaping, forest land utilization, and landfill covering. It is difficult to directly incorporate them into the agricultural land utilization system because they have certain limitations in substituting chemical fertilizers and realizing nutrient recovery. This subsection mainly discusses the advantages of cotreatment pathways of sludge via anaerobic digestion and incineration.

Sludge + kitchen waste or manure anaerobic digestion

A large-scale and stable commercial application model for anaerobic digestion of sludge has not yet been developed in China, and insufficient economic performance is one of the key reasons. According to analyses by water industry experts, there are approximately 60 completed sludge anaerobic digestion projects in China, yet less than half are in normal operation. Such projects are mainly deployed at medium and large wastewater treatment plants.[14] The wet sludge treatment capacity of a single project needs to exceed 35,000 tons per year. These projects require substantial capital investment and stringent process operation and management. The intrinsic feedstock characteristics of sludge constitute another constraint. Anaerobic digestion systems are sensitive to the organic matter content, volatile solids (VS) content, and pollutant levels of influent feed. Some municipal sludge in China features high contents of impurities and sand as well as low organic matter content. This leads to limited organic matter degradation and biogas production capacity during mono-digestion, making it difficult for benefits to offset up-front investment.

Codisposal of sludge + urban-rural wastes is expected to become an important pathway to improve the economic performance of anaerobic digestion. Municipal sludge has high moisture content (approximately 80%), with relatively limited organic matter content and energy output per unit of wet feedstock. It has a VS content of around 8%–13%, and its methane yield is approximately 10–45 m^3 per ton, indicating relatively limited biogas production potential. In contrast, both kitchen waste and cattle manure have a VS content above 14%, and their average methane yield per ton of wet feedstock ranges from 75 to 100 m^3 (see Exhibit 15).

Exhibit 15 **Organic matter content and methane yield of different urban-rural wastes**

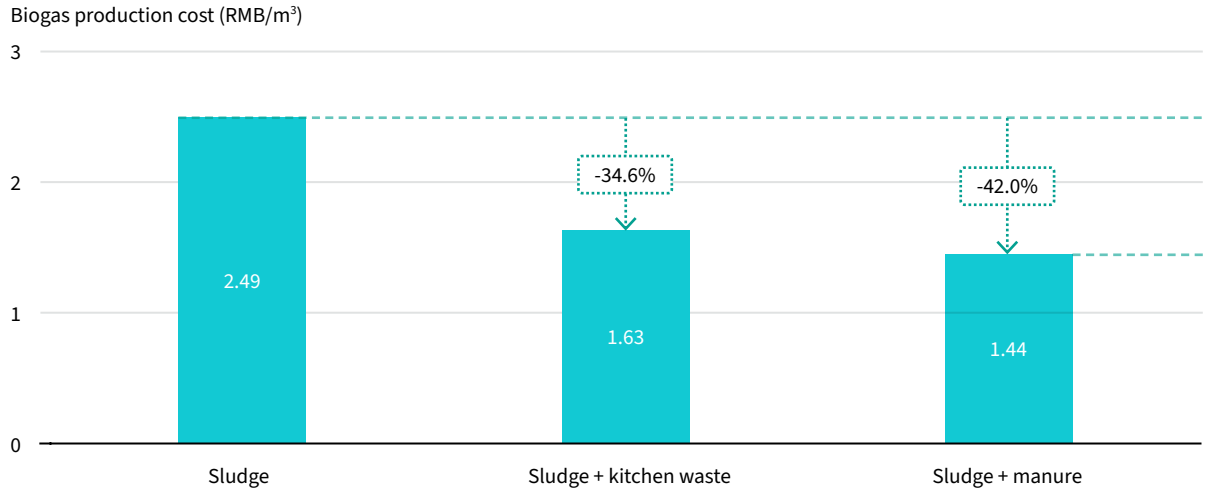


RMI Graphic. Source: Compiled by RMI from publicly available data

Co-anaerobic digestion of municipal sludge with high-organic-matter wastes such as crop straw, kitchen waste, and livestock and poultry manure can take advantage of the complementarity of different feedstocks in terms of organic matter content, nutrient elements, and degradation characteristics. This raises the organic load and biogas production efficiency of mixed feed, thereby increasing biogas yield and energy output per unit of wet feedstock and enhancing system stability. Meanwhile, the centralized treatment of multisource wastes in a single facility can amplify the scale effect of anaerobic digestion installations and reduce land, equipment, and operational expenditures required for separate treatment facilities for individual wastes.[15]

RMI estimated the unit biogas production cost for the sludge mono-digestion pathway and the sludge + co-disposal pathway. The scenario assumes an input of 10,000 tons of wet sludge for all three scenarios. In the sludge + kitchen waste scenario, kitchen waste is blended at a ratio of 4:1, while in the sludge + manure scenario, manure is mixed at a ratio of 3:1. In the scenario where sludge is used as the sole feedstock, the unit biogas production cost stands at approximately 2.5 RMB/m^3. By contrast, codisposal projects can cut the unit biogas production cost by more than 30%. The cost reduction mainly comes from increased biogas output, extra revenue from by-products such as grease and nutrient soil, and gate fees for treating manure and kitchen waste (see Exhibit 16).

Exhibit 16 **Economics of sludge and urban-rural waste co-anaerobic digestion projects**

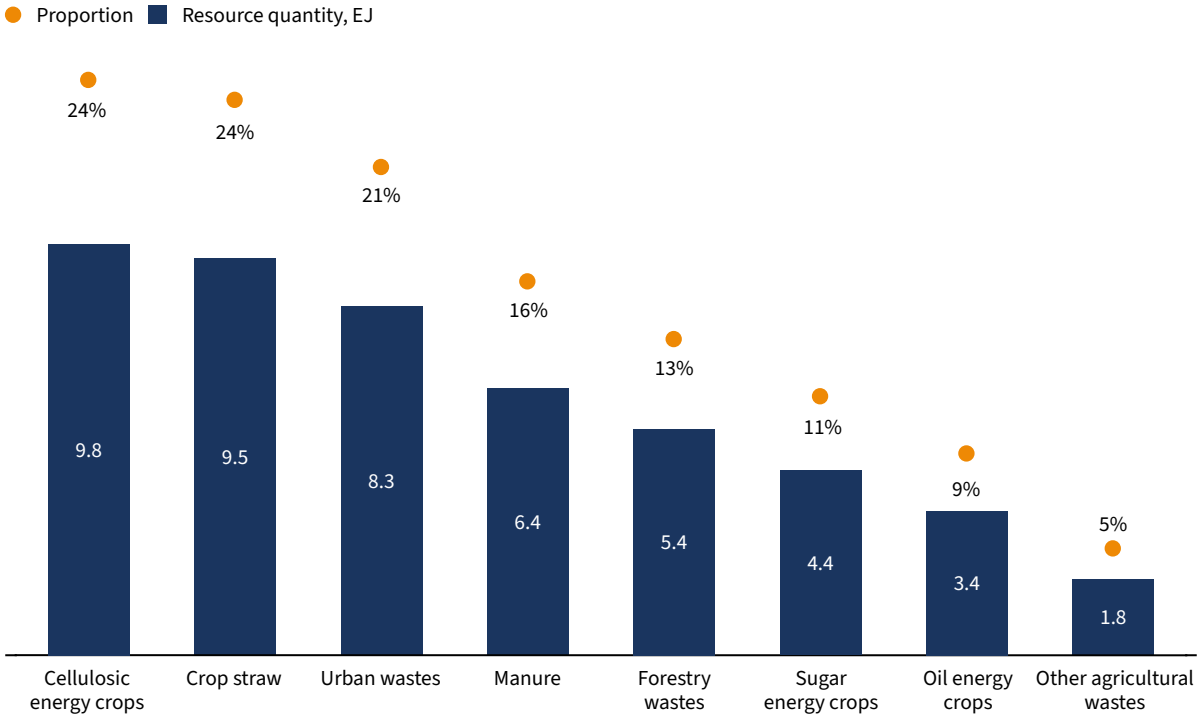


Note: This exhibit only illustrates the economics of co-anaerobic digestion projects. In practical engineering projects, due to differences in system design, as well as variations in feedstock quality and other factors, the blending ratio of waste resources such as kitchen waste and manure does not show a direct linear correlation with the incremental biogas yield. This study adopts limited engineering practices for illustration purposes, and no sensitivity analysis on blending ratios has been conducted.

RMI Graphic. Source: Compiled by RMI from publicly available data

Several enterprises in China have successfully constructed and operated codisposal projects for sludge and urban-rural wastes, showing broad development prospects (see Exhibit 17). For instance, the biomass waste treatment and disposal project in Shenzhen can treat 300 tons of sludge and 200 tons of kitchen waste per day, with a total investment of approximately RMB 250 million. It produces 8.76 million m^3 of biogas annually via anaerobic digestion and generates diversified revenues through power generation, waste heat recovery, and industrial grease recycling.[16] The cotreatment project for kitchen waste and municipal sludge in Zhenjiang City, Jiangsu Province, can process 300 tons of municipal sludge and 320 tons of kitchen waste per day, with a total investment of about RMB 358 million.[17] Diversified benefits are obtained from biogas power generation, crude grease, ammonium bicarbonate, and biochar soil recovery. China has abundant urban-rural organic waste resources including crop straw, livestock and poultry manure, and kitchen waste. The annual energy of crop straw in China is approximately 9.5 exajoules (EJ), urban waste around 8.3 EJ, and manure resources about 6.4 EJ,[18] which can provide a sufficient feedstock foundation for the co-utilization of sludge.

Exhibit 17 **Amount and composition of collectible biomass resources in China**



RMI Graphic. Source: Jiaoyue Wang et al., "Benefit Analysis of Multi-Approach Biomass Energy Utilization Toward Carbon Neutrality," 2023, **https://doi.org/10.1016/j.xinn.2023.100423**

Sludge + domestic waste incineration

The economic performance of independent incineration facilities for municipal sludge is relatively limited. After simple dewatering, municipal sludge in China generally has a moisture content of around 80%. Meanwhile, it features relatively low organic matter content and calorific value together with high ash content. Deep dewatering and drying are usually required prior to direct incineration to meet the requirements for stable combustion. A stand-alone sludge drying and incineration project also needs supporting facilities including for sludge drying, flue gas purification, and ash residue disposal. It not only requires substantial capital investment but also may consume a lot of energy for drying and have high operating costs. According to surveys by industry experts, calculated on a daily treatment capacity basis, the capital cost for mono-drying and incineration of sludge with approximately 80% moisture content in China ranges from 300,000 to 1 million RMB/ton of sludge, and the operating cost is generally about 200–300 RMB/ton of sludge.[19]

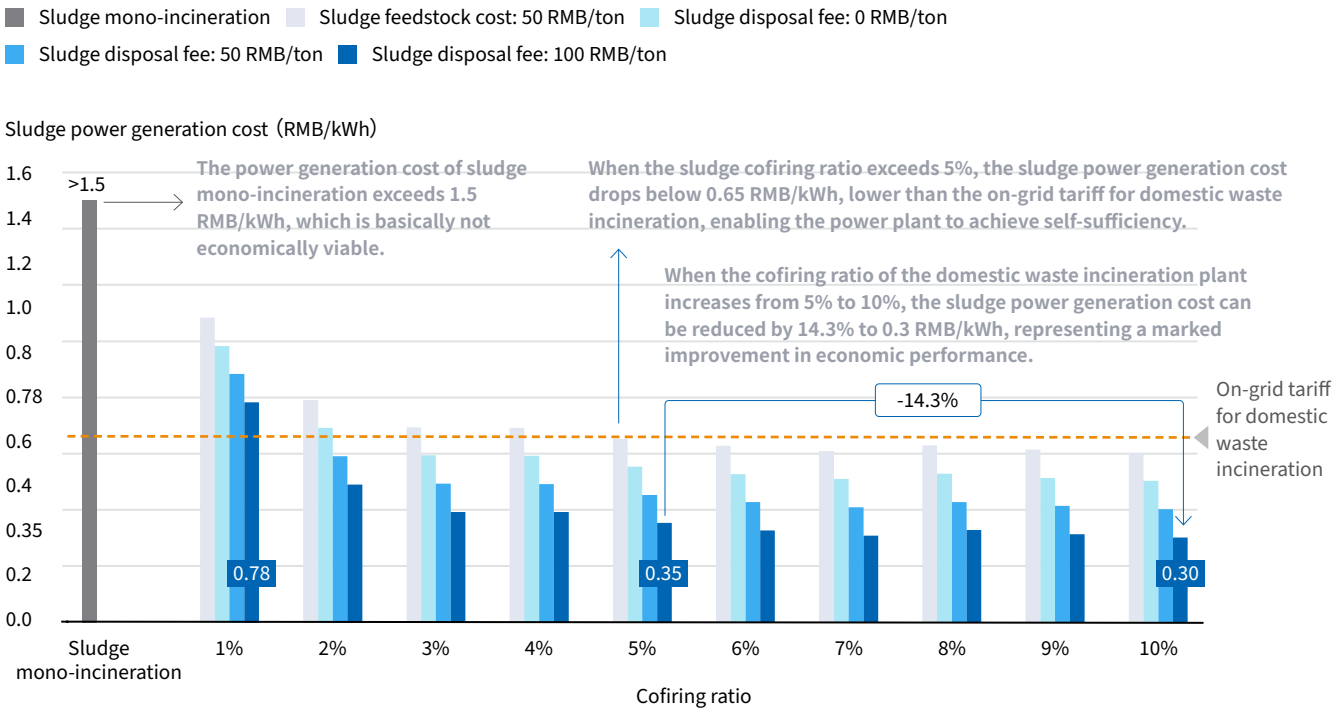
Compared with mono-incineration, co-incineration of sludge with domestic waste can improve sludge combustion conditions and make full use of existing solid waste disposal facilities. Domestic waste features high organic matter content and calorific value. When mixed with appropriately pretreated sludge, it can partially offset the adverse impacts on incineration caused by sludge's high moisture content and low calorific value. Studies indicate that when the cofiring ratio of sludge in domestic waste in China is controlled within 10%, the impacts on boiler operation are manageable and pollutant discharge requirements can be satisfied.[20] China has established a relatively mature treatment system for domestic waste incineration. Core facilities including incinerators, turbine power generation units, and flue gas purification systems can be directly adopted for sludge disposal. Additional investment is only required for newly built facilities for sludge receiving, storage, drying, and conveying.

Co-incineration of sludge boasts sound economic performance, mainly derived from the utilization of existing facilities, grid-connected power generation, and waste disposal revenues. Co-incineration of sludge with domestic waste is both technically and economically feasible in China. The investment cost is 200,000 RMB/ton of sludge, and the operation cost is 100–200 RMB/ton of sludge, resulting in cost savings of more than half compared to mono-incineration. Furthermore, power generation and sludge disposal fees can generate additional revenue for specific projects in operation.

Taking a medium-scale waste incineration plant (with an annual domestic waste treatment capacity of 500,000 tons) as an example, the research team configured small, medium, and large sludge pretreatment facilities (with capital costs ranging from RMB 3 million to RMB 15 million) according to different sludge cofiring ratios (1%–10%). The unit cost of power generation from sludge was estimated, and the results are shown in Exhibit 18. The power generation cost of mono-incineration is 1.5 RMB/kWh, making it economically unviable. For co-incineration, the power generation cost could be reduced to 0.65 RMB/kWh when the sludge cofiring ratio reaches 5%, which can almost achieve breakeven. Furthermore, the cost can be reduced significantly if sludge disposal fees are paid to the treatment operator.

On the basis of a guaranteed sludge disposal fee of 100 RMB/ton, as the cofiring ratio increases from 1% to 10%, the unit power generation cost of sludge (including disposal fees and power generation revenues) drops from approximately 0.78 to 0.30 RMB/kWh. When the cofiring ratio exceeds 5%, the cost falls below the benchmark on-grid power tariff of 0.65 RMB/kWh for waste incineration power, enabling the project to achieve profitability.

Exhibit 18 Power generation cost estimation for sludge mono-incineration and co-incineration with domestic waste

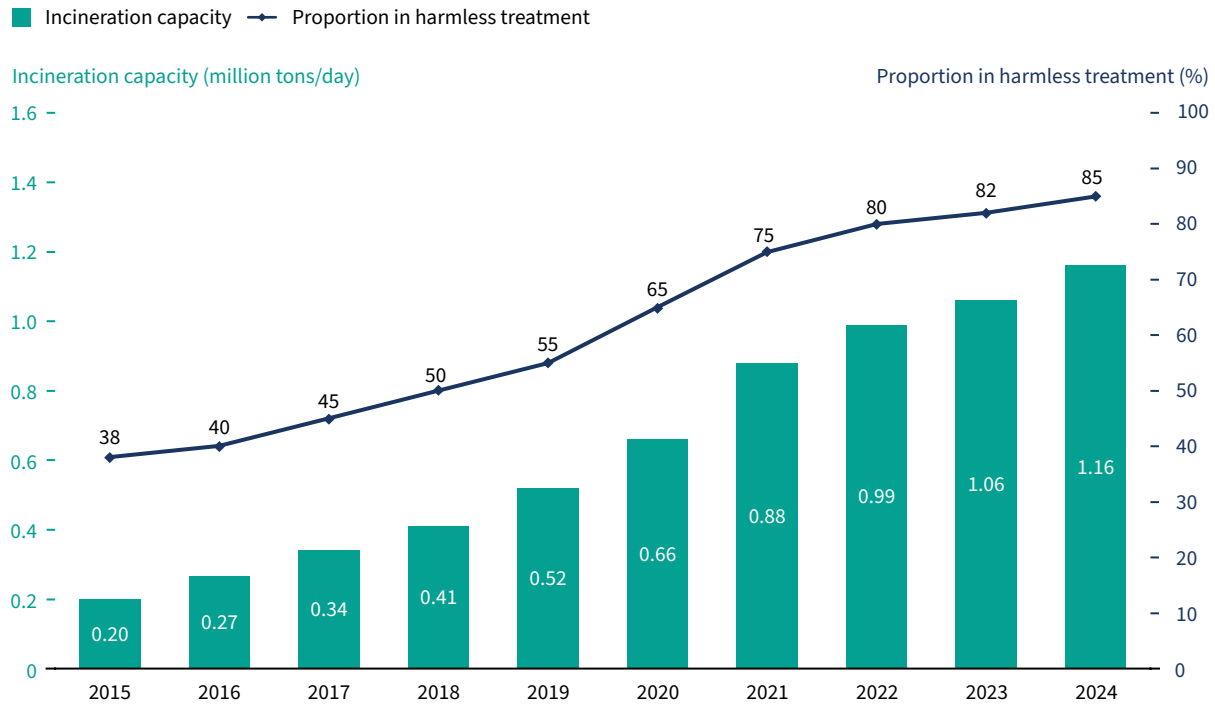


Note: This scenario assumes a medium-scale waste incineration power plant with an annual domestic waste treatment capacity of 500,000 tons. Sludge cofiring requires additional construction of small, medium, and large sludge pretreatment and conveying systems, with capital costs ranging from RMB 3 million to RMB 15 million. Meanwhile, cofiring will increase system operating costs, including chemicals consumption and system operation and maintenance expenses. Additional facilities for the harmless treatment of ash residue are also taken into consideration.

RMI Graphic. Source: RMI analysis

China's domestic waste incineration capacity has been continuously improving, creating opportunities for sludge to be incorporated into existing incineration systems. By the end of 2024, there were 1,137 operational domestic waste incineration plants nationwide. The daily domestic waste incineration capacity in cities and counties reached approximately 1.16 million tons per day, and the proportion of incineration in harmless treatment rose to around 85%.[21] This represents a nearly fivefold increase compared with about 200,000 tons per day in 2015, exceeding the target of 800,000 tons per day set in the 14th Five-Year Plan (2021–25).[22] With the rapid construction of domestic waste incineration facilities, China has built up substantial incineration treatment capacity (see Exhibit 19).

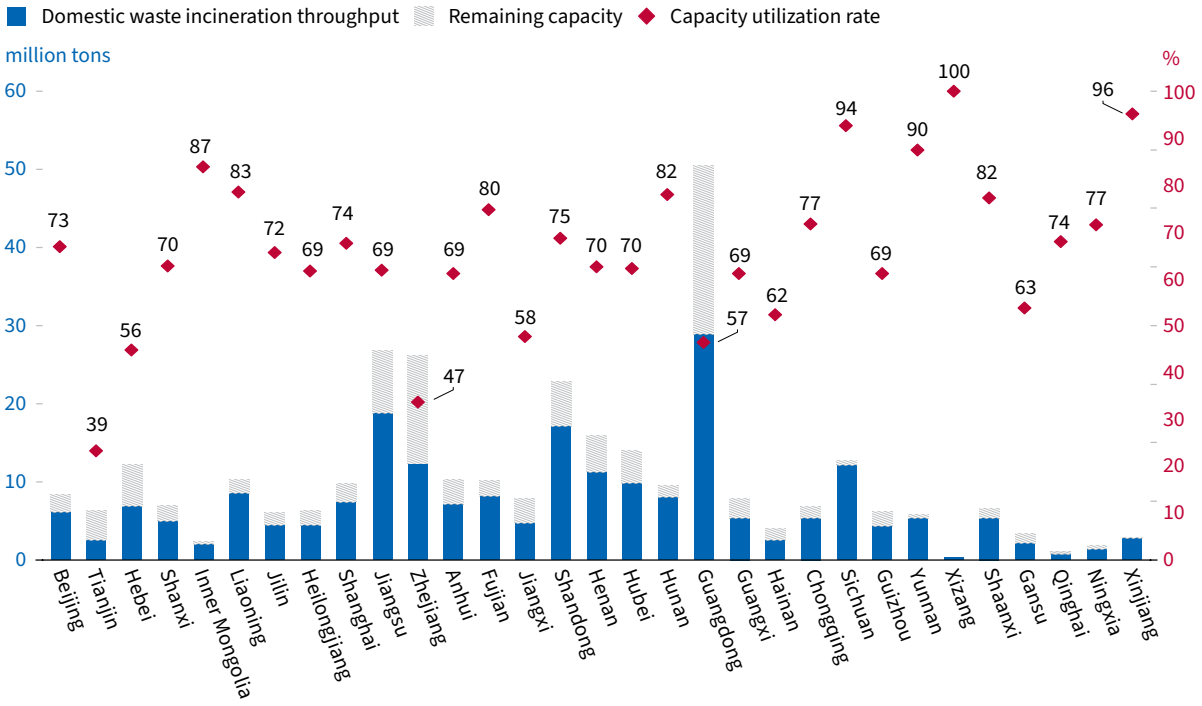
Exhibit 19 **Progress of domestic waste incineration capacity in China**



RMI Graphic. Source: *China Urban-Rural Construction Statistical Yearbook*, 2024

Some facilities are confronted with challenges such as slower growth in collected domestic waste volume and declining actual operational load. The national capacity utilization rate of domestic waste incineration stands at approximately 60%, and the sector is gradually entering a phase of optimized utilization of existing facilities. This provides broad scope for municipal sludge to be coprocessed within existing incineration systems (see Exhibit 20). Based on China's current municipal sludge production of 160,000 tons per day in China's cities and county seats, and assuming existing domestic waste incineration plants are equipped with a 5% cofiring capacity, these facilities can help treat 58,000 tons of municipal sludge per day, accounting for 36.3% of total sludge production. If the cofiring ratio is further increased to 10%, existing domestic waste incineration facilities can cotreat 116,000 tons of municipal sludge per day, making up more than 70% of total sludge production.

Exhibit 20 **Provincial domestic waste incineration capacity utilization in China (2024)**



RMI Graphic. Source: *China Urban-Rural Construction Statistical Yearbook, 2024*; RMI analysis

Improve market mechanisms and unlock the green and low-carbon value of wastewater resources

Climate value of achieving GHG emissions reduction

Municipal sludge resource utilization delivers substantial climate value, including cutting CO_2 emissions from fossil fuel combustion and mitigating methane emissions from sludge landfilling. However, the emissions reduction value of sludge resource recovery has not been fully monetized. Carbon markets, China Certified Emission Reduction (CCER), and relevant market mechanisms can be further leveraged. This subsection discusses the emissions reduction value and climate value realization approaches of various resource utilization routes, and assesses how carbon asset revenues affect sludge disposal costs and project economics. The key pathways include (1) biogas utilization from anaerobic digestion of municipal sludge, and (2) codisposal of municipal sludge in cement kilns.

CCER empowers anaerobic digestion of municipal sludge

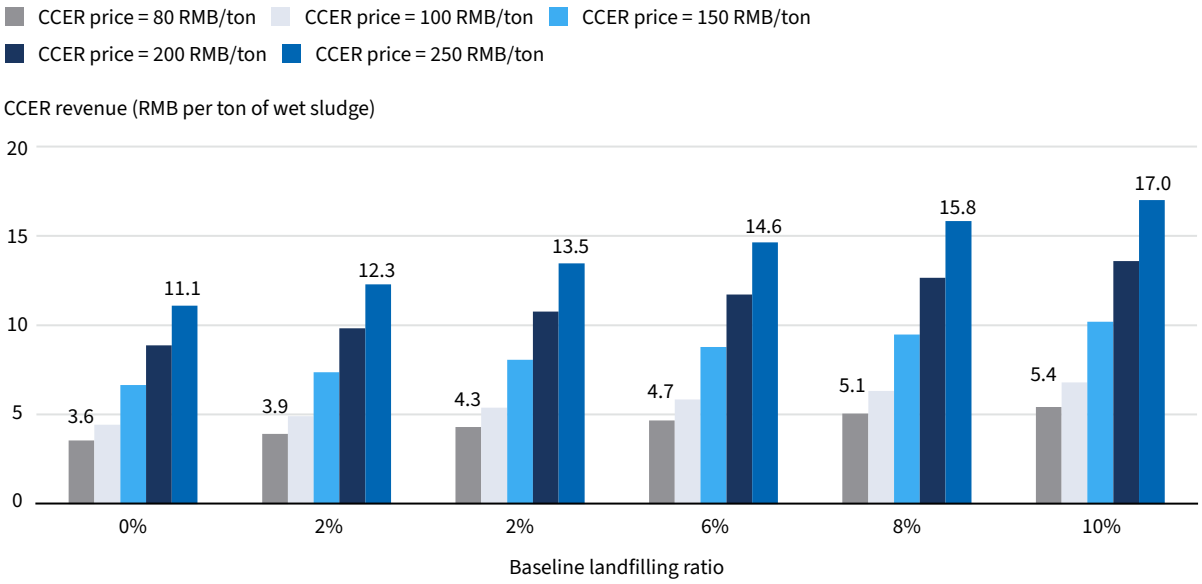
The CCER mechanism could be used to enhance the utilization of biogas generated from anaerobic digestion of municipal sludge. The energy benefits produced by existing sludge anaerobic digestion projects are already reflected in the reduced energy costs of wastewater treatment plants, while the value of GHG emissions reduction remains underexplored. China's wastewater sector is not covered by the national carbon market, and there are no mandatory emissions reduction targets, resulting in a general lack of market incentives across the industry. China's *Methane Emissions Control Action Plan* states that "qualified methane utilization and emissions reduction projects are supported to carry out voluntary GHG emissions reduction transactions,"[23] opening new prospects for methane reduction projects. China's Ministry of Ecology and Environment has released CCER methodologies for methane emissions reduction in the coal, oil and gas, and agricultural sectors. However, methodologies for the wastewater and sludge

sectors have not been formulated. Anaerobic digestion projects may become a key application direction in the future, providing direct economic incentives for emissions reduction at wastewater treatment plants.

CCER prices and the sludge landfilling ratio are key factors affecting the emissions reduction revenues of sludge utilization projects. The emissions reduction benefits generated by municipal sludge anaerobic fermentation projects fall into three categories: (1) heat and power produced through biogas energy utilization, which reduces CO_2 emissions from purchased energy at wastewater treatment plants; (2) reduced methane emissions from direct sludge landfilling; and (3) reduced GHG emissions from fossil energy consumption at wastewater treatment plants. Among these, methane emissions from direct sludge landfilling is one of the critical components for estimating baseline emissions in CCER projects. Because China's sludge disposal pattern is gradually shifting from landfilling to incineration and resource recovery, the sludge landfilling ratio is generally declining. This ratio under the baseline scenario directly determines project emissions reductions and economic performance.

The CCER trading price is another important factor influencing project emissions reduction revenues. Taking a thermal hydrolysis–anaerobic digestion biogas power generation project as an example, the research team analyzed the impacts of sludge landfilling ratio and CCER price on project economics (see Exhibit 21). Referring to China's CCER transaction price range of 50.8–107.4 RMB/ton CO_2e in 2025,[24] the analysis conservatively assumes a future average CCER transaction price of 80 RMB/ton CO_2e. Under a baseline scenario aligned with policy trends (i.e., a sludge landfilling ratio of 0%), the CCER revenue per ton of wet sludge reaches RMB 3.6, accounting for only 1.8% of China's unit sludge disposal fee (calculated at 200 RMB/ton of wet sludge), indicating relatively limited emissions reduction benefits. With the gradual increase in carbon prices in the future, the CCER revenue per ton of sludge could increase to RMB 11.1 per ton of wet sludge, delivering a certain economic incentive.

Exhibit 21 Impacts of sludge landfilling ratio under the baseline scenario on the economics of sludge biogas projects



Note: This study assumes a scenario where sludge is treated by thermal hydrolysis and anaerobic digestion coupled with biogas power generation facilities. All biogas-generated electricity is supplied to the wastewater treatment plant to displace purchased grid power. The associated CO_2 emissions are biogenic carbon and are not counted in total project emissions. The biogas yield of anaerobic digestion is 48 m^3 per ton of wet sludge, biogas methane concentration is 60%, biogas power generation efficiency is 2 kWh per m^3 of biogas, and the system methane fugitive rate is 0.5%.

RMI Graphic. Source: RMI analysis

Carbon trading empowers codisposal of sludge in cement kilns

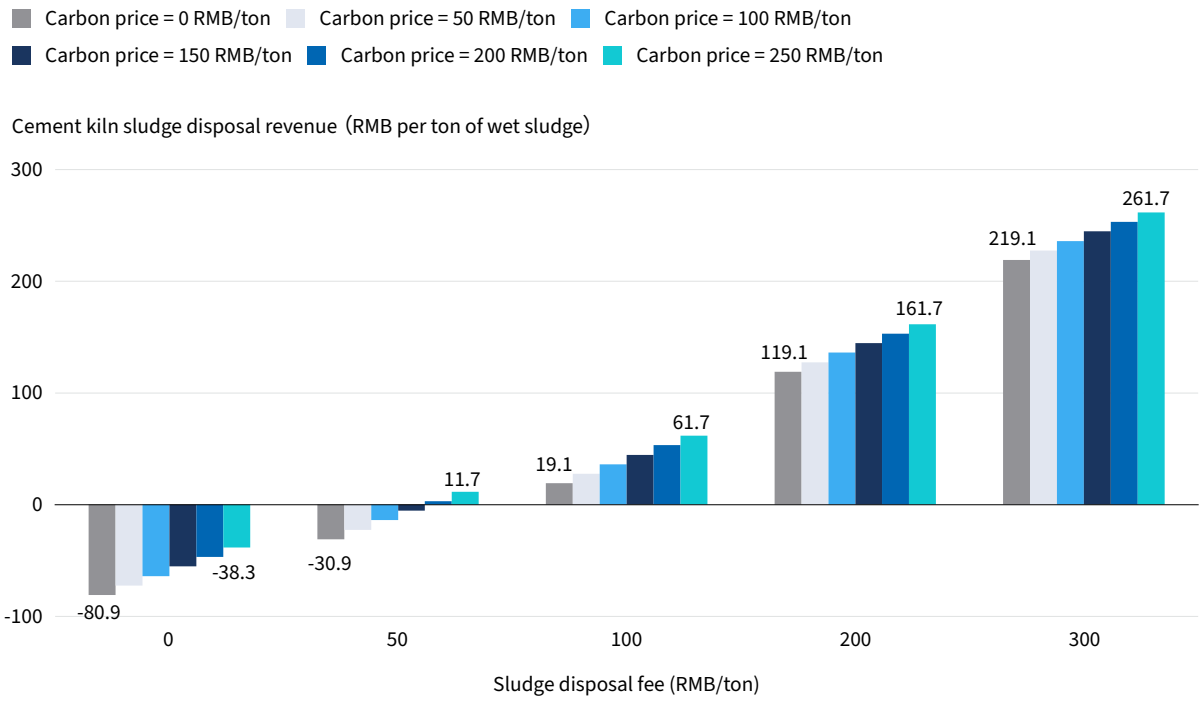
Codisposal of municipal sludge in cement kilns can leverage existing carbon market mechanisms to monetize emissions reduction value. After drying, municipal sludge experiences a substantial reduction in moisture content and can be fed into cement kilns as an alternative to fossil fuels such as coal, thereby cutting GHG emissions from energy-related activities during cement production. According to RMI calculations, assuming wet sludge (80% moisture content) is codisposed at 10% of the daily clinker capacity, approximately 170 kg of CO_2 emissions reduction can be achieved per ton of sludge coprocessed.

For a clinker production line with a daily capacity of 5,000 tons, the annual emissions reduction from sludge codisposal in cement kilns exceeds 30,000 tons. The cement sector is currently covered by the carbon market and uses the cap-and-trade system. Emissions reductions can generate revenues through carbon trading, further improving the economic performance of sludge codisposal in cement kilns. In addition to CO_2 emissions reductions recognized in the carbon market, cement kiln codisposal helps reduce sludge landfilling and associated methane emissions. Using a sludge landfilling ratio of 15%, codisposal of 1 ton of wet sludge in cement kilns avoids 8.4 kg of methane (equivalent to 235.6 kg CO_2) emissions. This additional emissions reduction benefit is far higher than the unit emissions reduction within the cement industry. Sludge codisposal in cement kilns accelerates the low-carbon transition of the cement sector and helps the wastewater sector mitigate climate risks arising from sludge disposal.

Improving the revenue of sludge disposal is critical for ensuring the stable operation of existing projects. On top of sludge disposal fees, the carbon market can further unlock the emissions reduction value of sludge codisposal in cement kilns and provide additional support for project economic performance. Codisposal of municipal sludge via cement kilns is a relatively mature and cost-controllable technical route in China. Based on the daily sludge disposal capacity, the project capital cost stands at approximately 150,000-200,000 RMB/ton of wet sludge. When operation and maintenance expenses are considered, the comprehensive sludge disposal cost ranges from 150 to 250 RMB/ton of wet sludge. In terms of revenues, the energy-saving income for cement kilns treating 1 ton of wet sludge is merely RMB 55–70, and sludge disposal fees — which are generally above 200 RMB/ton in China — constitute the primary source of project revenue. Combined with energy-saving income, cement kiln enterprises can roughly reach breakeven.

On this basis, the carbon market can further monetize the emissions reduction value generated by sludge codisposal. Under the scenario where the cement sector complies with carbon obligations, assuming a Chinese carbon market allowance price of 100 RMB/ton CO_2, the carbon price can raise project revenue by 17 RMB/ton of wet sludge, representing an approximately 14.3% improvement compared with the scenario without a carbon market. If calculated using a carbon price of 200 RMB/ton CO_2 for 2030, carbon trading revenue can further increase to 35 RMB/ton of wet sludge, boosting project economic performance by nearly one-third (see Exhibit 22).

Exhibit 22 Effects of carbon price and sludge disposal fee on the economics of cement kiln sludge co-disposal projects



Note: This scenario assumes that wet sludge accounts for 10% of the daily cement clinker capacity for codisposal. For a clinker production line with a capacity of 5,000 tons/day, 500 tons/day of municipal wet sludge (80% moisture content) is codisposed. After drying, the moisture content of sludge is reduced to approximately 30%, and the sludge is mixed with coal before being fed into the kiln for combustion.

RMI Graphic. Source: RMI analysis

China's cement industry has substantial demand for raw materials and fuels, which provides a broad foundation for sludge disposal. As the world's largest producer and consumer of cement, China boasts a cement clinker capacity of over 2 billion tons,[25] with annual CO_2 emissions reaching 1.37 billion tons and total fuel demand as high as 170 million tons of standard coal,[26] creating room for the codisposal of sludge. Previous RMI research indicates that approximately 17% of clinker production lines are capable of coprocessing solid waste,[27] with around 45 lines equipped for sludge codisposal, delivering an annual treatment capacity of roughly 3.5 million tons and accounting for 6% of China's municipal sludge generation.[28] Based on the RMI's estimates, the existing codisposal capacity of cement kilns can avoid 30,000 tons of methane emissions from sludge landfilling each year (equivalent to 925,000 tons of CO_2). As carbon prices increase, the emissions reduction value generated by using sludge to replace fossil fuels will increase, offering additional market incentives for the cement sector to scale up sludge codisposal.

Breaking barriers to green fuel sales and innovating trading mechanisms

Biogas from industrial wastewater can be further upgraded into biomethane after purification, expanding the market revenues from resource utilization. This pathway relies on existing wastewater treatment infrastructure and already boasts strong cost competitiveness. Previous research by RMI shows that the unit cost of biomethane production in China using livestock manure, straw, food waste, and other feedstocks ranges from 4.4 to 11.5 RMB/m^3.[29] Compared with the residential and commercial natural gas price of 2–5 RMB/m^3, biomethane's market competitiveness remains limited. The high production cost of

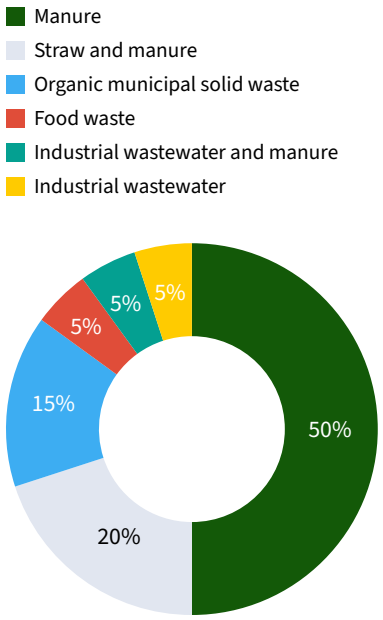
the above pathway arises not only from feedstock acquisition but also from fixed costs including facility investment and land procurement. In contrast, industrial wastewater treatment facilities are generally equipped with anaerobic treatment units, which are core facilities for pollutant removal and have already been deployed during the construction of wastewater treatment plants. Some projects are also fitted with biogas recovery and utilization systems, substantially cutting the incremental capital investment required for biomethane production. According to RMI analysis, the average production cost of biomethane derived from industrial wastewater is 1.5–2 RMB/m^3, making it potentially the most cost-competitive biomethane development pathway at the current stage.

The development of green fuel certification mechanisms opens a new pathway for unlocking the market value of biomethane produced from industrial wastewater. Globally, green fuel certification systems are evolving and their applications are expanding. International organizations like the International Sustainability and Carbon Certification and Roundtable on Sustainable Biomaterials are providing certification for green attributes such as sustainable feedstock sources and GHG emissions performance. Meanwhile, relevant certification systems and market mechanisms in China are continuously advancing, with multiple national and industrial standards for biomethane being issued, leading to an increasingly mature framework.

At the international certification level, 19 projects in China have obtained biomethane certification. Nevertheless, these projects mainly adopt agricultural and forestry residues as feedstocks, and certification practices for biomethane produced from resource recovery of industrial wastewater remain relatively limited (see Exhibit 23). As more industrial wastewater–based biomethane projects undergo green fuel certification, their feedstock sources, production processes, and emissions reduction attributes can be standardly identified and traced, laying a foundation for subsequent participation in green fuel markets and the exploration of attribute trading mechanisms.

Exhibit 23 Internationally certified biomethane projects in China and associated feedstock types

Feedstock types	Enterprise name	Location
Food waste	Hanlan (Foshan) New Energy Operation Co., Ltd.	Foshan City, Guangdong
Livestock and poultry manure	Biaofa Ecology (Juancheng) Co., Ltd.	Heze City, Shandong
	Biaofa Ecology (Juye) Co., Ltd.	Heze City, Shandong
	Chengdu Hongji Borun Environmental Protection Technology Co., Ltd.	Chengdu City, Sichuan
	Jiangsu Huai'an Guofeng Qingyuan Biogas Co., Ltd.	Huai'an City, Jiangsu
	Shanghai Shenji Langneng Environmental Protection Technology Co., Ltd.	Shanghai
	Shenyang Liaozhong Shanda Biomass Technology Co., Ltd.	Shenyang City, Liaoning
	Wangkui Juneng Biomethane Co., Ltd.	Suihua City, Heilongjiang
	Welle (Haiyan) Bioenergy Co., Ltd.	Jiaxing City, Zhejiang
	Zhoukou Chengzhi Biomass Energy Co., Ltd.	Zhoukou City, Henan
Organic municipal solid waste	Chongqing Aitifu Green Energy Co., Ltd.	Zunyi City, Guizhou
	Shanghai Environment Group Renewable Energy Operation Management Co., Ltd. Fengxian Branch	Shanghai
	Shanghai Laogang Waste Comprehensive Development Co., Ltd. Phase III	Shanghai
Straw, manure	Anhui Wanbo Energy Technology Co., Ltd.	Bengbu City, Anhui
	Heilongjiang Boneng Green Energy Technology Co., Ltd.	Daqing City, Heilongjiang
	Heilongjiang Boneng Green Energy Technology Co., Ltd.	Suihua City, Heilongjiang
	Shanghai Shenji Langneng Environmental Protection Technology Co., Ltd.	Jinshan District, Shanghai
Brewing wastewater	Luzhou Hangfa Energy Investment Co., Ltd.	Luzhou City, Sichuan
Food industry wastewater, manure	Funan Linhai Ecological Technology Co., Ltd.	Fuyang City, Anhui

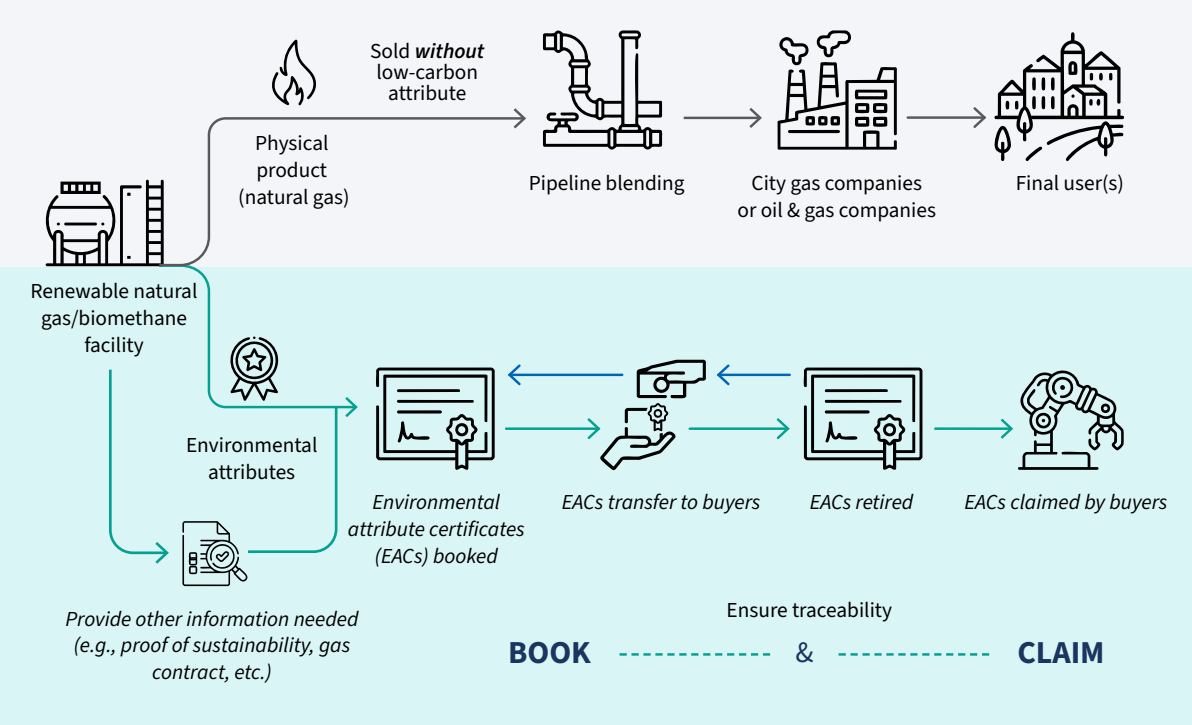


Note: This exhibit only lists projects with valid certifications and excludes expired certifications.
RMI Graphic. Source: International Sustainability and Carbon Certification

Continuous improvement of environmental attribute certification and trading mechanisms helps further unlock the green value of biomethane, expand downstream consumer markets, and enhance the economic performance of industrial wastewater biogas upgrading projects. Unlike biogas power generation, which is mostly consumed on site, upgraded biomethane can be supplied to more end-use energy scenarios including industrial production and urban gas supply. In practical applications, however, biomethane production projects and energy-consuming enterprises are often located in different regions. Reliance solely on end-to-end transactions may be constrained by transmission and distribution costs and pipeline availability.

In recent years, rising demand for green fuels has driven the global development of relevant environmental attribute certification and trading frameworks, creating new pathways for cross-regional consumption of green fuels. Among these, the book and claim mechanism separates the physical green fuel product from its certified environmental attributes, enabling the tracking, transfer, and retirement of such environmental attributes (see Exhibit 24). This allows off-site consuming enterprises to purchase and retire corresponding green attributes without physically using green fuel produced by a specific project. The book and claim mechanism has already been implemented in the aviation sector. The Sustainable Aviation Buyers Alliance, co-initiated by RMI, facilitates corporate participation in the aviation fuel market through the purchase of sustainable aviation fuel attribute certificates, applying the book and claim mechanism to cross-regional consumption of sustainable aviation fuels. This mechanism is expected to break the geographical constraints of physical biomethane supply, enlarge the potential consumer market for biomethane, and create opportunities for industrial wastewater biogas upgrading projects to capture green premiums.

Exhibit 24 **Illustrative book and claim model for biomethane**



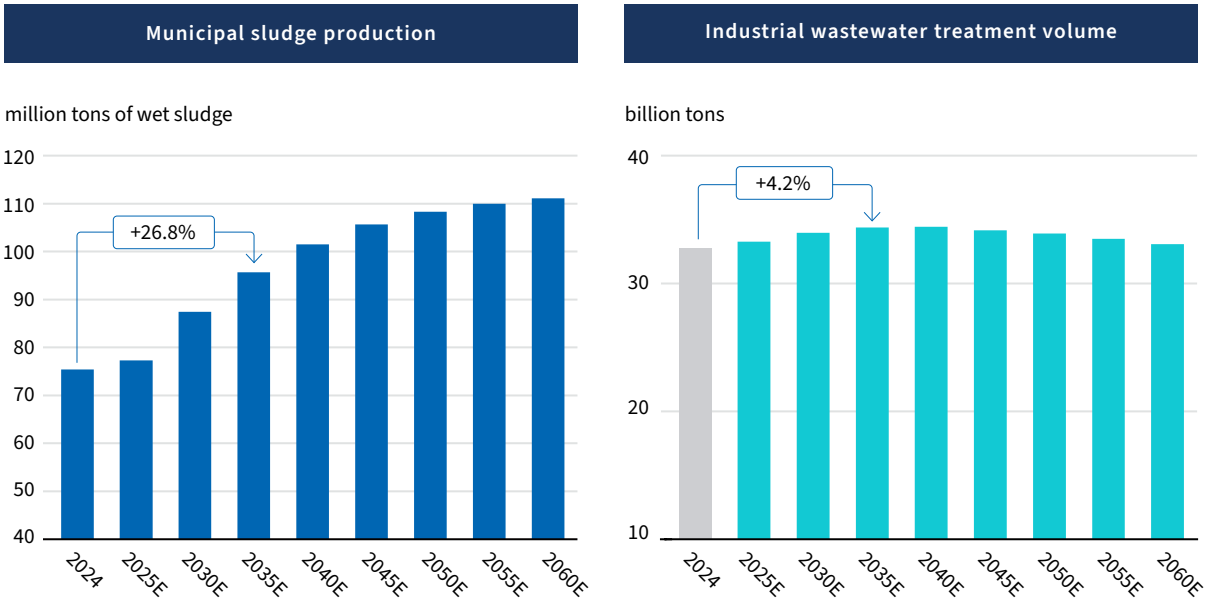
RMI Graphic. Source: RMI analysis

4. Prospects and Action Recommendations for Resource Recovery of Wastewater Systems

Development trends and pathways outlook

China will continue to generate large volumes of municipal sludge and industrial wastewater. Although this creates persistent pressure for methane emissions reduction, it also opens development opportunities for resource recovery. According to RMI analysis, domestic wastewater output and industrial wastewater treatment volumes in China will keep rising in the short term. By 2035, the annual output of municipal wet sludge will exceed 95 million tons, a 26.8% increase compared with 2024, and the annual industrial wastewater treatment volumes will increase 4.2%, reaching 34.1 billion tons (see Exhibit 25). By 2060, China's annual municipal sludge output will exceed 110 million tons, while the annual industrial wastewater treatment volumes will gradually decrease to 33 billion tons due to advancements in industrial water-saving technologies. Against the backdrop of substantial wastewater and sludge volumes, resource recovery needs to shift from utilization within individual facilities and single-resource exploitation toward coordination across all links of the industrial chain. This is an important development direction for resource recovery in the wastewater system.

Exhibit 25 **Forecast of municipal sludge production and COD removal volume of industrial wastewater in China**

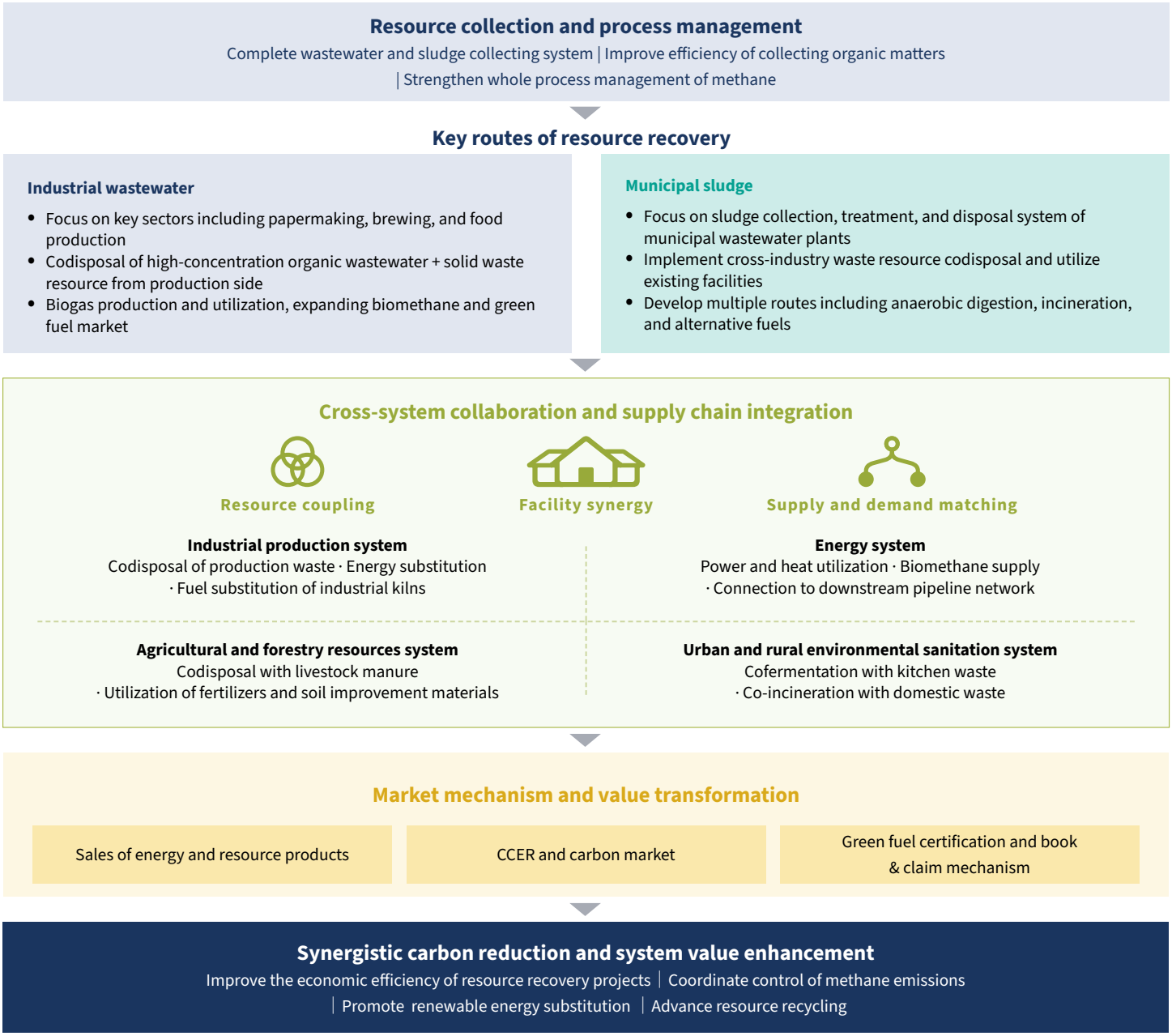


RMI Graphic. Source: *China Urban-Rural Construction Statistical Yearbook;* RMI analysis

From the perspective of the entire industrial chain, wastewater systems first need to improve the supply conditions of available resources and the methane management performance of the systems. At the source collection and treatment stages, the effective collection of pollutants could be enhanced, alongside strengthened monitoring and process control of methane emissions. By upgrading wastewater pipelines and reducing infiltration of extraneous water and organic matter loss, treatment facilities can concentrate more organic materials into sludge and wastewater, providing a stable feedstock base for subsequent anaerobic digestion. For methane generated during wastewater treatment, gas collection and emissions control could be further reinforced to mitigate fugitive methane. Future improvements could start from the front end of wastewater collection and treatment. Pipeline infrastructure will need to be upgraded. Combined sewers will need to be reduced to lower organic matter loss and dilution during transportation.

On the basis of improved resource supply conditions, China can further focus on technological pathways with concentrated resources and stable utilization scenarios, and explore coupled development modes such as industrial coordination and resource synergy. Industrial wastewater generated from light industries features high organic concentration and good biodegradability. Its treatment boundary lies within industrial facilities, which facilitates centralized treatment and integration with on-site energy demand of production processes, creating favorable conditions for energy recovery. Municipal sludge, by contrast, has large and stable output. It can be centrally treated and co-utilized using existing industrial facilities such as cement kilns and waste incineration plants, avoiding capital expenditure on new equipment and facility lock-in (see Exhibit 26).

Exhibit 26 Coordinated development routes for methane emissions reduction and resource recovery in wastewater systems



RMI Graphic. Source: Compiled by RMI

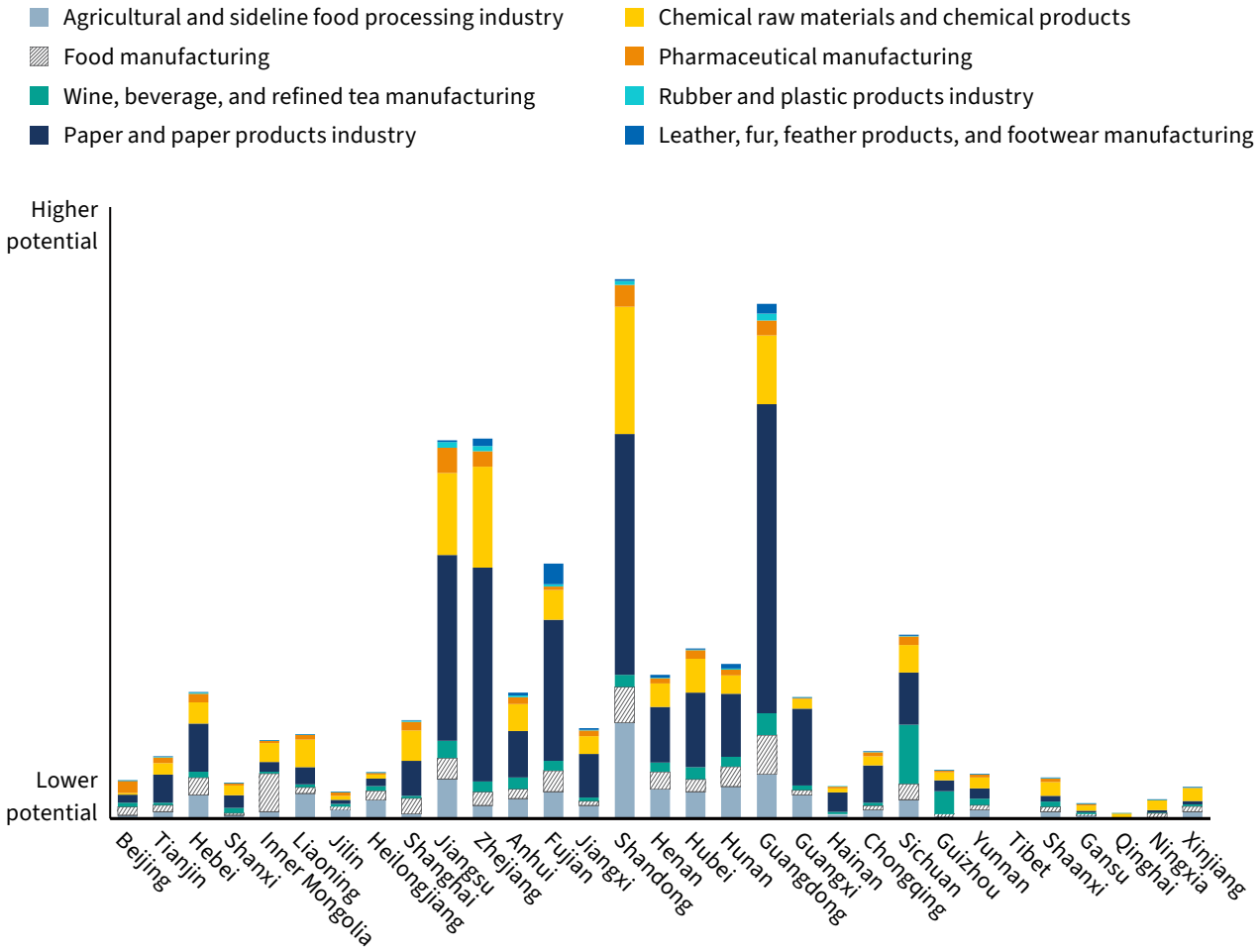
Industrial wastewater

For methane resource recovery from industrial wastewater, regional industrial foundations and resource concentration could be fully considered. Demonstration projects could be prioritized in regions with large resource volumes, favorable recovery conditions, and clear downstream demand. Based on the national wastewater treatment status by sector, provincial industrial economic activity scale, and biogas generation potential of wastewater across different industries, RMI estimates that China's methane resource recovery potential from industrial organic wastewater was approximately 2 billion m^3 in 2024 (see Exhibit 27).

Guangdong, Shandong, Jiangsu, Zhejiang, and Fujian together account for 51.6% of the national potential. East China and South China jointly make up 63.5%, forming the core regions for biogas development from industrial wastewater in China. Provinces including Shandong, Jiangsu, Zhejiang, and Fujian host dense industrial parks with concentrated high-organic-load industries such as papermaking, chemicals manufacturing, and agricultural and sideline food processing. These regions enjoy favorable conditions for centralized wastewater collection, anaerobic treatment, and biogas utilization, and could be prioritized for large-scale development in the near term.

In Central China, Henan, Hubei, and Hunan are dominated by papermaking, agricultural and sideline food processing, and food manufacturing. Park-level projects relying on industrial clusters can be rolled out. Although the overall potential of Southwest China is lower than that of eastern regions, Sichuan and Guizhou feature distinctive liquor industries. Wastewater from liquor-making has high COD concentration and great resource recovery value. A targeted development model matching local industrial structure is recommended to promote codigestion of distillers' grains and wastewater. Northeast and Northwest China have relatively low overall potential. Demonstration projects may be deployed at enterprises or industrial parks with large-scale wastewater output, focusing on food and chemicals industries.

Exhibit 27 **Provincial- level potential of industrial wastewater resource recovery in China**



Note: The resource recovery potential in this exhibit covers eight industrial sectors under the Industrial Classification for National Economic Activities. The theoretical biogas production capacity from wastewater is adopted as the primary evaluation indicator, which does not represent the methane emissions reduction potential of industrial wastewater in each sector.

RMI Graphic. Source: RMI analysis

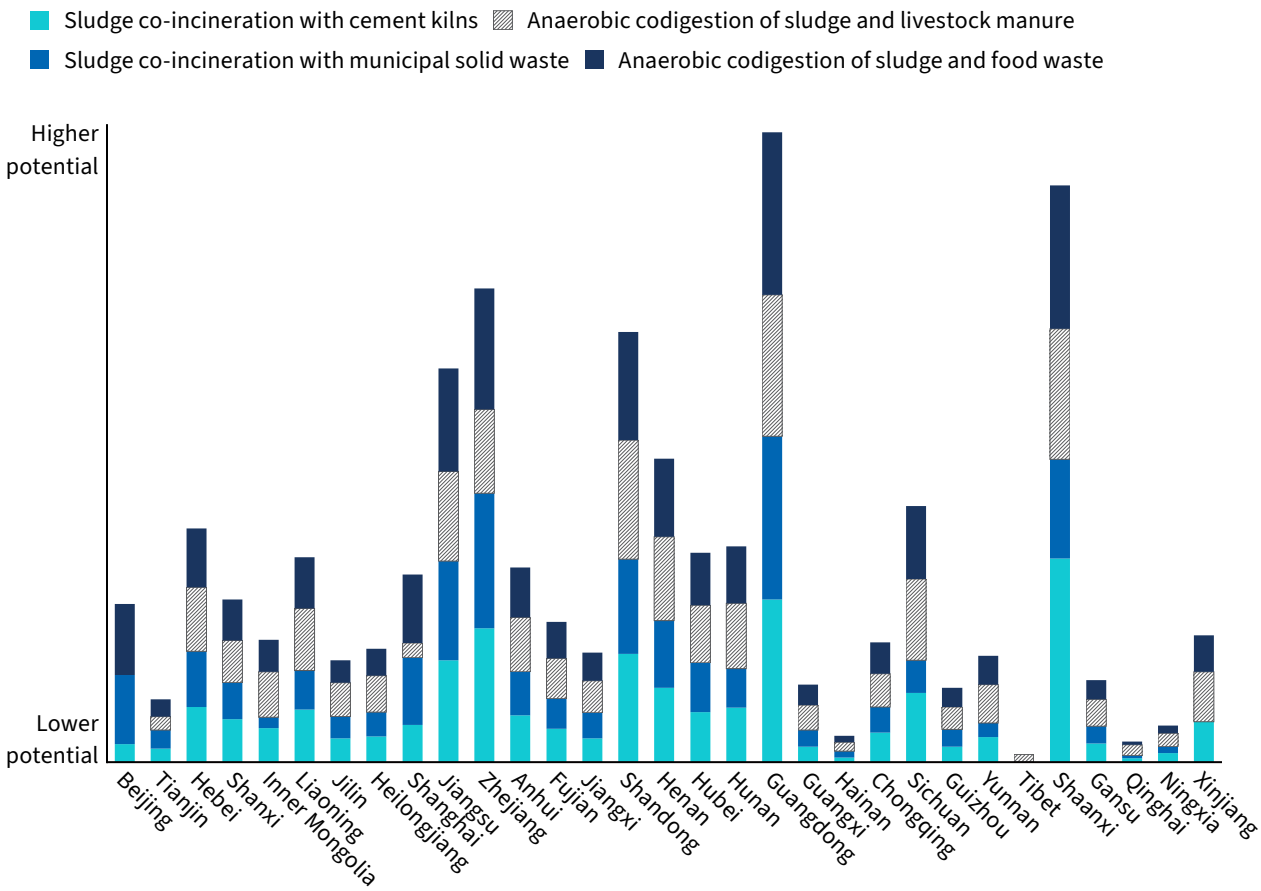
High-organic-load industries such as papermaking, food, wine, and beverage sectors, where differentiated utilization pathways can be explored tailored to industry characteristics, are priority areas for methane resource recovery from industrial wastewater. The papermaking industry shows high potential in Guangdong, Shandong, Jiangsu, Zhejiang, Fujian, Guangxi, and other provinces. Enterprises and industrial parks are highly concentrated in these regions.

Anaerobic recovery can be promoted based on existing wastewater treatment facilities, and further co-utilization with organic wastes such as waste pulp and paper sludge can be explored. The food industry boasts prominent potential in Shandong, Liaoning, Heilongjiang, Henan, Hubei, and other provinces. Slaughter, starch, food processing, and other enterprises may prioritize on-site biogas utilization. Baijiu industries are concentrated in Sichuan, Guizhou, and other regions. Wastewater from liquor production contains high concentrations of organic matter. Co-anaerobic digestion with organic wastes such as distillers' grains can be implemented to improve system efficiency. For large industrial parks and individual enterprises, priority could be given to substituting self-used fossil fuels and purchased electricity with biogas. For projects with daily biogas output of 10,000 m^3 or more, stable gas supply, and downstream demand, biogas can be further purified into biomethane to expand application scenarios including industrial fuel, transportation fuel, and gas pipeline injection. Meanwhile, green fuel certification and the book and claim mechanism can be adopted to lower downstream sales barriers and improve project economics.

Municipal sludge

China's sludge resource recovery potential exhibits significant regional disparities. Eastern coastal regions with concentrated populations and economic activities boast larger resource volumes and a sound foundation for co-utilization (see Exhibit 28). Provinces with high sludge generation are mainly located in Eastern and Central China, where economic activities are intensive and urban wastewater treatment infrastructure is relatively complete. These regions also have mature wastewater treatment and sludge disposal facilities, laying a foundation for further advancement of sludge energy recovery and resource utilization. Rather than simply expanding sludge treatment capacity, future planning for sludge resource recovery should focus on better aligning existing sludge treatment facilities with nearby organic waste streams, municipal solid waste treatment facilities, and industrial kilns. This includes considering their geographic proximity, available treatment capacity, and potential for resource and energy integration. Large-scale demonstrations could be prioritized in regions with substantial sludge volume, favorable codisposal conditions, and clear downstream consumption demand.

Exhibit 28 **Resource recovery potential and key technological pathways of municipal sludge by province in China**



Note: The resource recovery potential in this exhibit takes provincial sludge generation, cement clinker production capacity, unused capacity of municipal solid waste incineration, and resource volumes of livestock manure and food waste as primary evaluation indicators. The promotion potential of each co-utilization pathway is determined by weighted scoring.
RMI Graphic. Source: RMI analysis

China's municipal sludge resource recovery potential shows marked regional agglomeration characteristics. Eastern coastal provinces and some economically concentrated and populous central-western provinces could be designated as key regions for large-scale resource recovery development. Nationwide, sludge generation volume is closely correlated with economic development level, urbanization rate, and the scale of wastewater treatment facilities. Eastern coastal provinces including Guangdong, Zhejiang, Shandong, and Jiangsu, together with central-western provinces with relatively concentrated populations and industries such as Shaanxi, form the key regions for municipal sludge resource recovery in China. These regions have a large base of sludge output, alongside well-established wastewater collection and treatment systems and robust infrastructure carrying capacity, providing solid resource and facility foundations for large-scale sludge resource recovery.

In contrast, some western and island provinces with low population densities and small industrial scales have relatively limited total sludge resources and less room for large-scale development. Therefore, the future industrial layout could not follow a nationwide homogeneous promotion model. Instead, priority would be given to key provinces with abundant sludge resources and favorable downstream consumption conditions. Site-specific codisposal and energy recovery pathways can be selected to build demonstration projects with scale effects and regional industrial clusters, and mature models can be gradually extended to other regions.

Codisposal of sludge using cement kilns and municipal solid waste incineration facilities serves as an important pathway to expand sludge disposal capacity in regions with high industrialization and urbanization levels. For provinces with large-scale sludge generation, the key to resource recovery development lies not merely in sludge resources themselves, but in whether effective spatial matching and capacity connection can be achieved with surrounding existing facilities such as cement kilns and municipal solid waste incineration plants. Eastern coastal provinces including Guangdong, Zhejiang, Jiangsu, and Shandong have both substantial sludge output and well-established cement kiln and municipal solid waste incineration infrastructure. These regions possess favorable development conditions for the two codisposal pathways, and regionalized, large-scale sludge codisposal models can be explored on a priority basis.

Some central and western provinces have relatively limited municipal solid waste incineration facilities but large cement clinker production capacity. Thus, they are more suitable to expand sludge codisposal capacity relying on existing industrial kilns. The co-incineration of sludge could not simply follow a single technical route. Instead, based on the scale, load level, and spatial distribution of local cement kilns and waste incineration facilities, priority could be given to utilizing existing industrial infrastructure to expand sludge disposal capacity. This approach avoids massive investment in new dedicated disposal facilities while improving the utilization efficiency of existing infrastructure, and achieves synergistic benefits of sludge volume reduction, resource recovery, and energy substitution.

Co-anaerobic digestion of sludge with urban and rural organic wastes is suitable for developing differentiated energy utilization models for organic wastes in light of regional agricultural production and urban consumption characteristics. Provinces with large-scale livestock breeding such as Shandong, Henan, Sichuan, and Hebei are rich in livestock manure resources. Priority can be given to exploring co-anaerobic digestion of sludge + livestock manure. Complementary components among different organic wastes can improve anaerobic digestion efficiency and support large-scale supply of energy products including biogas and biomethane. For coastal provinces with highly concentrated population and urban consumption such as Guangdong, Jiangsu, and Zhejiang, food waste generation is large, and the collection, transportation, and centralized treatment systems are relatively well-developed. Such regions are more suitable for developing co-anaerobic digestion of sludge + food waste.

In the future, demonstration projects could be deployed based on provincial resource endowments to systematically match sludge with surrounding high-organic-content waste resources. Prioritizing regions with concentrated resources, sound facility foundations, and clear consumption demand for energy products will drive the transition from single-waste disposal to synergistic resource recovery of multisource organic wastes.

Action recommendations

Realizing resource recovery of wastewater and sludge will generate economic value, advance the development of a circular economy, cut methane emissions, and support the achievement of China's dual carbon goals. China has built up a large-scale wastewater treatment capacity. Nevertheless, methane emissions control and resource recovery within wastewater treatment systems are still in the initial stage. Restricting factors include unclear emissions inventories, excessive capital costs for some projects, poor upstream–downstream linkage, and difficulty in materializing green value. Relevant practices are currently limited to local pilot demonstration projects, and large-scale application remains a long way off. To transform wastewater treatment from conventional end-of-pipe treatment into an integrated system that synergistically achieves pollution reduction, carbon mitigation, and resource circulation, it is

advisable to further improve institutional arrangements, strengthen industrial coordination, refine market mechanisms, and foster a complete industrial ecosystem based on existing policies and technologies. This will gradually unlock the key links spanning emissions accounting, technology deployment, and resource value realization. To this end, we recommend five actions:

1. **Consolidate the policy foundation: Establish a policy and standard system for the wastewater treatment sector.** China has issued a number of policy documents to promote methane emissions control and resource recovery in wastewater treatment systems, laying a foundation for industrial transformation. Next, relevant standards for methane monitoring and accounting of wastewater systems could be improved, forming a closed-loop management framework integrating accounting, monitoring, reporting, and verification. Meanwhile, a green and low-carbon policy and standard system covering the whole process of sewer network, septic tank, wastewater treatment, sludge disposal, and resource recovery could be developed. Also, emissions reduction performance and resource recovery level could be incorporated into the performance evaluation criteria for wastewater treatment enterprises, the technological pathways and targets for methane emissions reduction and resource recovery of wastewater and sludge could be clarified, and emissions reduction outcomes and resource recovery efficiency could be the key foundations for facility operation and retrofitting. Appropriate financial subsidies could be provided to wastewater treatment enterprises, especially small and medium-sized ones, that meet policy standards to facilitate corporate transformation investment and policy implementation. In addition, the coordination among policies related to methane emissions reduction, wastewater resource recovery, circular economy, and energy utilization could be strengthened. On this basis, differentiated targets for methane emissions control and resource recovery could be formulated in light of regional variations in wastewater treatment scale, resource endowments, and utilization conditions to provide institutional support for the sector's transition from end-of-pipe treatment to full-process low-carbon and resource-oriented management.

2. **Strengthen industrial coordination: Build cross-departmental and cross-industry coordination mechanisms.** Resource recovery of wastewater and sludge requires participation from multiple sectors including wastewater treatment, energy, industry, and agriculture. Proper coordination across industries can synergize cost reduction and efficiency improvement. The cotreatment of high-concentration organic wastewater and organic wastes within industrial parks could be promoted to improve resource utilization efficiency and enhance carbon reduction effects. Codisposal of municipal sludge with high-organic-content wastes such as straw, food waste, and livestock manure would boost biogas yield and energy output. Wastewater treatment enterprises are encouraged to collaborate with waste incineration operators. The idle capacity of existing municipal solid waste incineration facilities can be used for cocombustion of municipal solid waste and sludge in proportion for power generation, which can substantially cut sludge disposal costs and achieve project profitability. Because wastewater and sludge treatment and disposal fall under the jurisdiction of different government authorities, a cross-departmental coordination mechanism covering authorities such as development and reform, ecological environment, housing and urban-rural development, energy, water affairs, and agriculture could be developed. Cross-departmental data sharing and integrated management could be strengthened across wastewater treatment, sludge disposal, and resource recovery links. Cooperation between wastewater treatment enterprises and other relevant industries will be promoted by governments, and the green and low-carbon transition of wastewater treatment will be advanced in tandem with urban infrastructure construction, energy utilization, and circular economy development.

3. **Improve market mechanisms: Unlock green value and stimulate endogenous momentum for resource recovery.** Market mechanisms serve as a vital instrument to guide investment, incentivize technological innovation, and advance methane emissions reduction and resource recovery in wastewater treatment systems. At present, poor circulation between the products generated from wastewater and the sludge resource recovery projects and downstream market demand persists. Product value has not been fully materialized, and revenues often fail to cover the high up-front capital investment and operational costs of projects. Moving forward, relevant product qualification standards could be refined, barriers to product circulation could be removed, green product certification could be promoted, and green premiums could be created. In addition, accelerating the development of CCER methodologies tailored to the wastewater treatment sector would help convert environmental benefits such as methane emissions reduction and fossil fuel substitution into identifiable, tradable green value. This would diversify the monetization channels for methane control and resource recovery in wastewater treatment systems, raise the economic returns of projects, and incentivize enterprises to pursue voluntary transition.

4. **Foster an industrial ecosystem: Integrate upstream and downstream industrial chains to advance large-scale development of resource recovery.** The key to the large-scale deployment of wastewater resource recovery lies in whether resource-based products can secure stable and sustained downstream application markets. It is necessary to gradually explore alternatives to the traditional development model confined within the boundaries of wastewater treatment plants and build a complete industrial chain covering recovery, processing, conversion, and end-use application centered on resources such as biogas, sludge, and nutrients. Wastewater and sludge resources in China feature marked regional disparities. Eastern coastal regions boast prominent resource recovery potential, a high concentration of upstream and downstream industries, and a higher level of marketization, which is conducive to leveraging the advantages of industrial clusters. Key provinces with abundant sludge resources and favorable downstream consumption conditions could be prioritized. Site-specific codisposal and energy recovery pathways could be adopted. Long-term cooperation between wastewater treatment enterprises and companies from energy, agriculture, industrial parks, and resource recycling sectors could be strengthened. Challenges regarding the market uptake of wastewater and sludge-derived products can be addressed through product standards, supply–demand matching, and stable procurement mechanisms. Demonstration projects with scale effects and regional industrial clusters can be established, and mature models can be gradually rolled out to other regions.

5. **Improve financial support: Leverage green financial instruments to reduce corporate investment costs.** Resource recovery projects for wastewater and sludge require large up-front investment and have long payback periods. Nevertheless, their low-carbon and circular economy attributes align with sustainable development. Green credit, green bonds, carbon finance, and other innovative financial instruments could be adopted to guide financial institutions such as banks to participate in the transformation and upgrading of the wastewater treatment sector and cut the transition costs of wastewater treatment enterprises. Meanwhile, wastewater and sludge resource recovery projects could be included in the green financial support catalogue. Refining project evaluation and risk-sharing mechanisms and establishing a multilevel financial support system could help lower corporate financing costs and risks and promote the sound and sustainable development of the sector.

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